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UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Grid Reliability and Resilience Pricing	)	Docket No. RM18-1-000

REPLY COMMENTS OF EXELON CORPORATION[1]

The Commission should follow a three-step approach to address the generation resilience concern identified by the Secretary of Energy. *First*, the Commission should take immediate action to ensure that unjust and unreasonable market rules do not send inaccurate price signals to fuel-secure resources that are critical to any long-term solution to system resilience. This includes (a) directing PJM to complete energy market reforms within 90 days and (b) declaring that units receiving Zero Emissions Credits or other support payments, which preserve existing nuclear units in economic distress, will not have their capacity market bids mitigated. These actions will not fully solve the problem of resilience, but will help alleviate the immediate economic challenges to nuclear units and other fuel-secure resources.

There is widespread support among commenters for the prioritization of energy price formation issues.[2] Moreover, there is already a record that would allow the Commission to

[1] In addition to these comments, Exelon has prepared answers to certain of the questions placed in the docket by FERC Staff. These answers are attached to the conclusion of these reply comments.

[2] *See, e.g.*, United States Department of Energy, Staff Report to the Secretary on Electricity Markets and Reliability 107-117 (August 2017), *available at* https://energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf ("DOE Staff Report"); Comments of Edison Electric Institute, Docket No. RM18-1 (Oct. 23, 2017) ("EEI Comments") at 4-6; Initial Comments of the Electric Power Supply Association, Docket No. RM18-1 (Oct. 23, 2017) at 51-53; Initial Comments of PJM Interconnection, L.L.C. on the United States Department of Energy Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) ("PJM Comments") at 39-49; Letter of Professor Willian W. Hogan

determine under Section 206 that the current market rules are not just and reasonable in PJM.[3] The Commission should so find and direct PJM to adopt a solution within 90 days. PJM's energy markets are based on the economic principle that the marginal cost of the unit of supply needed to satisfy demand should set the price. Yet the current market rules violate this basic economic principle because units like coal and nuclear are not necessarily permitted to set the locational marginal price, even when they are needed to serve load. The rules thus are not just and reasonable and must be revised.[4]

Second, the Commission should create a process for gathering and assessing data from RTOs that will shed light on the system's vulnerabilities and potential impacts resulting from those vulnerabilities. No commenter disputes, in particular, the system's increasing vulnerability to gas pipeline interruptions, as nuclear and coal resources retire and are largely replaced by gas resources. And no one disputes the extreme toll to our society that would result from a prolonged and widespread outage resulting from a high impact, low frequency ("HILF") event, such as an interruption to multiple gas pipelines. Accordingly, the problem warrants further study. In its opening comments, Exelon provided a detailed list of the information that should be requested and proposed time frames for RTO responses.

Third, the Commission should use that data, together with threat analysis from the national security and intelligence communities, to establish a design basis threat ("DBT") that can inform

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to Mr. Stu Bresler, Attachment B to PJM Comments at 2-3; Comments of NRG Energy, Inc., Docket No. RM18-1 (Oct. 23, 2017) at 10-11.

[3] PJM Comments at 48.

[4] Further, given that PJM has so plainly acknowledged price formation as a problem in PJM, a point with which many commenters and economists agree, the Commission would be justified in ordering PJM to develop and implement price formation improvements as set forth in PJM's Comments.

cost-effective market reforms. Stakeholders largely agree that resilience is a concept distinct from reliability or resource adequacy. Resilience refers to the system's ability to prepare for, operate through, and recover from HILF events.[5] But as many stakeholders point out, the Commission lacks metrics to evaluate resilience.[6] A DBT will provide a benchmark against which resilience can be measured, and a basis for developing specific solutions for the RTOs to implement. Once that work is complete, Exelon supports PJM's proposal for the Commission to direct each RTO to submit specific reforms to address any resilience-related issues identified in an RTO, with a "deadline that is in the near term."[7] Exelon proposes a deadline of 90 days from the time the Commission establishes a design basis threat.

Each of these steps is moderate in scope and can be accomplished quickly. And the Commission should pursue them expeditiously. Our system's vulnerability is real and the threats grave, and the potential consequences of inaction are unimaginable. Hostile actors are constantly

[5] PJM Comments at 18-19. HILF events are frequently referred to as Black Swan events because the probability of the event occurring is difficult to determine. Unlike traditional reliability events based upon weather or forced outage rates which can be probabilistically determined based upon historical data, a HILF event (for example, a cyber-attack by a nation-state or other malicious actor) may not be forecastable. For this reason, HILF events not only encompass incidents that are expected to occur infrequently, but also events that cannot be forecasted because of significant unknowns. Resilience also differs from reliability in having to account for the underlying nature of man-made threats, which differ from hurricanes and other familiar natural hazards. Unlike hurricanes, adversaries are intelligent and adaptable. Adversaries will also be able to selectively target points of special vulnerability in energy systems, including those related to fuel resilience and gas-electric system interdependencies. Initiatives to define the attributes of resilience and assess measures to strengthen them will need to incorporate these non-traditional risk factors.

[6] Comments of PJM at 20; Initial Comments of AES on the United States Department of Energy Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) at 13; Initial Comments of the Energy Storage Association on the United States Department of Energy Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) at 10; Initial Comments of Large Public Power Council on the United States Department of Energy Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) at 3; Initial Comments of Environmental Defense Fund on the United States Department of Energy Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) at 40-41.

[7] Comments of PJM at 48.

probing for weaknesses in our electric grid. A single successful attack that leaves large swaths of the United States without power for an extended period would destroy our Nation's ability to ensure law and order, leave tens of millions of Americans without access to safe drinking water, food, or medical care, devastate our military capabilities, and result in an untold number of deaths.

Together, these steps are essential to achieving a resilient grid at the least cost for consumers. The first step strengthens markets by ensuring that they operate efficiently and consistent with basic economic principles, and that fuel-secure resources are not disadvantaged by flawed market rules. The second two steps do not prejudge what type of solution might be necessary or most cost-effective. Instead, they are focused on understanding the nature of the problem we face and developing a design standard around which solutions can be framed. Once the Commission has sufficient information before it to identify the vulnerabilities that must be addressed, it should consider a range of potential solutions for the design basis threat that can achieve resilience at least cost to customers. RTOs may be able to propose appropriate market-based solutions to accomplish those goals—and they should be encouraged to do so. But in the event that market-based solutions are unworkable or too costly, the Commission should not foreclose the possibility of other solutions. If a market-based solution is unavailable, the stakes are too high to reject a cost-based alternative simply on account of loyalty to a pro-market ideology.[8]

[8] *See, e.g.*, *ISO-New England Inc.*, 144 FERC ¶ 61,204, PP 9-11 (2013) (order conditionally accepting ISO-NE's out of market Winter Reliability Program oil procurement).

I. Grid Resilience is an Urgent Problem in the Eastern RTOs That Prior Reforms Have Not Addressed.

A. The Resource Mix in the Eastern RTOs Is Changing as Fuel-Secure Resources Retire, Creating New Vulnerabilities.

The resource mix in the eastern RTOs is changing rapidly, as many gigawatts of nuclear and coal capacity retire and are replaced largely by gas generation. In the PJM region, 90 percent of the new installed generation over the last five years has been gas-fueled, as is more than 90 percent of planned generation in the interconnection queue.[9] As gas generators enter, resilient baseload units leave.[10] Exelon noted in its initial comments that the loss of nuclear generation in particular has been dramatic. Between 2002 and 2016, 4,666 MW of nuclear generating capacity announced retirement, approximately 4.7 percent of the U.S. total.[11] Another eight nuclear reactors with 7,167 MW of capacity have announced retirement plans since 2016.[12]

The growing prevalence of gas generators, many of which are dependent upon a small number of pipelines for fuel, creates new risks to the system. As Dr. Stockton explains in his attached Supplemental Testimony (attached as Exhibit A), the emerging resource mix in the Eastern RTOs is increasingly susceptible to "common mode failure," in which a large fraction of

[9] For the PJM RPM auctions from 2015/16 through 2020/21, 90% of new cleared installed capacity has been either natural gas-fired combustion turbines or combined-cycle generators (approximately 32.4 out of 36.2 total GW of new build, reactivated, or uprated capacity). *See* PJM Interconnection L.L.C., *2020/21 RPM Base Residual Auction Results*, Table 8, http://www.pjm.com/-/media/markets-ops/rpm/rpm-auction-info/2020-2021-base-residual-auction-report.ashx?la=en.

[10] Comments of FirstEnergy Service Company *et al.* in Support of the Grid Reliability and Resilience Pricing Notice of Proposed Rulemaking, Docket No. RM18-1 (Oct. 23, 2017) ("FirstEnergy Comments") at 24-28 (listing recent retirements of baseload units); Comments of ClearPath Foundation, Docket No. RM18-1 (Oct. 23, 2017) at 9.

[11] DOE Staff Report at 29.

[12] *Id*. at 30.

generation resources are susceptible to the same vulnerability.[13] In PJM, 11,000 MW of gas generation is dependent upon a single pipeline.[14] Thus, a single disruptive event—whether it is a physical attack by terrorists, a cyber-attack by a foreign government, or an adverse weather event—can undermine a significant share of the generating capacity serving the Nation's most populous region. Moreover, because pipelines are increasingly dependent upon electricity to function properly, a widespread outage could result in further fuel supply disruptions, leading to an even more widespread outage. Coordinated attacks on multiple pipelines would have far more severe consequences.

No steps have been taken to address the grid's increasing vulnerability due to the growing interdependence of gas supply and electric generation. The Secretary of Energy identified these risks in the NOPR that initiated this proceeding.[15] Other experts concur. According to NERC, "[n]atural gas-fired generation faces greater susceptibility to fuel supply chain disruption than coal and nuclear generation."[16] A disruption of the pipeline network could dramatically reduce the quantity of natural gas available for generators. Using a power-flow simulation, NERC found that "that 18 out of 19 areas studied experience transmission or operational challenges during an extreme event" involving disruption to natural gas supply facilities.[17] ISO-NE likewise

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[13] Supplemental Testimony of Paul Stockton, attached as Exhibit A, at 12 ("Stockton Supplemental Testimony").

[14] PJM Reliability Analysis Update (Sept. 14, 2017), *available at* http://pjm.com/-/media/committees-groups/committees/teac/20170914/20170914-reliability-analysis-updates.ashx, pp. 8-11.

[15] Dep't of Energy, Grid Resiliency Pricing Rule, 82 Fed. Reg. 46,940, 46,941 (2017) ("DOE NOPR").

[16] NERC Comments at 9.

[17] NERC November 9, 2017 Board of Trustees Agenda, Item 8c, available at http://www.nerc.com/gov/bot/Agenda%20highlights%20and%20Mintues%202013/Board_Open_Meeting_November_9_2017_Agenda_Package.pdf.

highlighted this concern at the October 2017 Commission open meeting when it presented its Winter 2017-2018 Operations and Market Performance update. It noted that "*the ability to meet energy needs is at risk if gas cannot be supplied to gas-fired generators.*"[18] ISO-NE repeated these concerns in comments in this docket.[19] PJM, meanwhile, is studying the effects of a single gas pipeline outage, but that is not enough: PJM should also consider the effects of multiple pipeline failures occurring simultaneously.[20]

Currently, generation developers and owners have no economic incentive to consider the systemic consequences of their investment decisions.[21] RTOs have not attempted to place an economic value on a resource's contribution to system resiliency.[22] Moreover, PJM's market

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[18] Presentation of ISO-NE, October 19, 2017, available at https://www.ferc.gov/CalendarFiles/20171019125657-6-ISONE.pdf.

[19] Comments of ISO-NE Inc., Docket No. RM18-1 (Oct. 23, 2017) at 8-9 ("ISO-NE is concerned about the region's gas dependence").

[20] *See generally* NERC 2016 Long-Term Reliability Assessment, at p. 21 (Dec. 2016) ("As part of future transmission and resource planning studies, planning entities will need to more fully understand how impacts to the natural gas transportation system can impact electric reliability."); NERC, *Severe Impact Resilience: Considerations and Recommendations*, May 2012, p. 1; NERC and the Department of Energy, *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System*, June 2010.

[21] As Chairman Chatterjee noted as his press conference on October 13, 2017, "Accurately valuing resilience is not a zero-sum game. Compensating base-load generation does not equate to destruction of markets. On the contrary, I think it's a step toward accurately pricing contributions of all market participants."

[22] Comments of Kinder Morgan, Inc. on the Rule Proposed by the Secretary of the Department of Energy, Docket No. RM18-1 (Oct. 23, 2017) at 6-7; Comments of the National Rural Electric Cooperative Association, Docket No. RM18-1 (Oct. 23, 2017) at 3; Comments of the PSEG Companies, Docket No. RM18-1 (Oct. 23, 2017) at 5-7; FirstEnergy Comments at 22-30; Comments of Invenergy Renewables LLC and Invenergy Thermal Development LLC, Docket No. RM18-1 (Oct. 23, 2017), at 5; Comments of Algonquin Gas Transmission, LLC, Docket No. RM18-1 (Oct. 23, 2017) at 4-6; Comments of the National Rural Electric Cooperative Association, Docket No. RM18-1 (Oct. 23, 2017) at 13-14; Rulemaking Comments of the Nuclear Energy Institute, Docket No. RM18-1 (Oct. 23, 2017) ("NEI Comments") at 13-17; Initial Comments of Talen Energy Corporation, Docket No. RM18-1 (Oct. 23, 2017) at 5-11; Motion to Intervene and Comments of Peabody Energy Corporation, Docket No. RM18-1 (Oct. 23, 2017) at 3-8;

design has aggravated the problem, by systematically undercompensating fuel-secure, baseload resources in the energy markets. As a result, private investment decisions are not aligned with the public interest in homeland security. The Commission cannot afford to ignore this issue, which could have devastating consequences for our society, as described above and in Dr. Stockton's testimony.

B. The Commission Should Reject Commenters' Arguments for Inaction.

Commenters opposed to action advance four basic arguments. *First*, some claim there is no reason to be concerned about resiliency—either because the threats are unproven, or because the Commission has already taken steps, such as the Capacity Performance ("CP") reforms in PJM, to enhance reliability, making further steps unnecessary. *Second*, some contend that the Commission should ignore generation-related vulnerabilities because there are also transmission- and distribution-related vulnerabilities that need to be addressed. *Third*, some commenters argue that the costs of implementing the DOE proposal will be very high.[23] *Fourth*, the PJM Independent Market Monitor ("PJM IMM"), using cherry-picked and misleadingly presented data, asserts that the potential changes to the resource mix are overstated, because nuclear generators by and large recover their costs from the markets. Each of these arguments should be rejected.

Comments of Murray Energy Corporation in Support of Proposed Rule, Docket No. RM18-1 (Oct. 23, 2017) at 2-7.

[23] *See, e.g.*, Comments of Rockland Capital, LLC, *et al.*, Docket No. RM18-1 (Oct. 23, 2017) at 12-13; Comments of the PJM Independent Market Monitor, Docket No. RM18-1 (Oct. 23, 2017) ("PJM IMM Comments") at 4-8; Evaluation of the DOE's Proposed Grid Resiliency Pricing Rule, Attachment A to Joint Industry Comments Opposing the DOE Proposal, Docket No. RM18-1 (Oct. 23, 2017) at 24-25.

1. Resiliency Threats Are Real, and Neither the Capacity Performance Reforms Nor High Reserve Margins Address Resiliency.

Some commenters oppose the DOE's proposal on the ground that there is no genuine threat to resiliency. The Commission should reject this view. Those with expertise concur that resiliency must be made a priority. NERC, the entity whose statutory mandate is to "conduct periodic assessments of the reliability and adequacy of the bulk-power system in North America,"[24] has emphasized the resilient and reliable generation furnished by coal and nuclear units, and the threat to the stability of the bulk power system resulting from those units' retirements. Specifically, NERC explained that "[b]urgeoning reliance on natural gas-fired generation as a replacement for coal and nuclear generation decreases fuel diversity and increases single source fuel dependency."[25] Thus, "[t]he electric sector's growing reliance on natural gas raises concerns regarding the ability to maintain BPS reliability when facing constraints on the natural gas delivery systems."[26] Not only are gas-fueled resources susceptible to supply interruptions that can affect numerous generators simultaneously, but the nuclear and coal generators that are being replaced "provide substantial essential reliability services as a function of large spinning generators and governor control settings, along with reactive support for voltage control."[27]

Dr. Paul Stockton's testimony, submitted with Exelon's initial comments, confirms NERC's observations.[28] Dr. Stockton is one of the country's leading experts on grid resiliency

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[24] 16 U.S.C. §§ 824o(g).

[25] *See* NERC Comments at 10.

[26] *Id.* at 11 (quoting NERC, *Short-Term Special Assessment: Operational Risk Assessment with High Penetration of Natural Gas-Fired Generation*, at pp. 10-11 (May 2016), *available at* http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC% at 12).

[27] *See* NERC Comments at 8.

[28] Ex. A to Comments of Exelon ("Stockton Initial Testimony").

and national security. From June 2009 until January 2013, he was the Assistant Secretary of Defense for Homeland Defense and Americas' Security Affairs. He was responsible for Defense Critical Infrastructure Protection and led the creation of the Department's Mission Assurance Strategy. He served as the Domestic Crisis Manager for the Department of Defense (DOD) and was responsible for Defense continuity of operations. He also was the principal civilian advisor to the Secretary of Defense for providing Defense support to Federal Emergency Management Agency, the Department of Energy (DOE) and other Federal departments in Superstorm Sandy, Hurricane Irene, and other disasters.[29]

Dr. Stockton outlined the existing risk to national security from overreliance on natural gas. He concluded that "[r]isks of mutually-reinforcing failures between gas and electric systems have grown."[30] These risks create the possibility of a "black sky" power outage which "would inflict immense disruption on national security, the U. S. economy, and public health and safety."[31] He recommends that the Commission take immediate efforts to study the problem and develop a design basis threat to help evaluate the risk.[32]

Other industry commenters also concur. PSEG, for example, supports the DOE's efforts "to immediately address the erosion of resiliency of our electric grid due to the risk of premature retirements of baseload generation."[33] This trend, particularly in PJM, is resulting in a resource mix placing "greater reliance on natural gas-fired generating resources and exposing the power

[29] *Id.* at 2.

[30] *Id.* at 8.

[31] *Id.* at 9.

[32] *Id.* at 18-19.

[33] PSEG Comments at 2.

supply portfolio to a greater risk of single mode failure."[34] As PSEG notes, maintaining a resilient and diverse electric grid has important consequences for both human health and national security.[35] AEMA encourages the Commission to "[o]pen a proceeding on resilience with the objectives of defining the needs of resilience on a regional basis and how those needs have evolved."[36] ISO-NE's recently-released 2017 Regional System Plan makes much the same point, noting that "[p]reserving the reliable operation of the system will become increasingly challenging with potential retirements, the increased reliance on natural gas resources" [37]—which are estimated to rise from 44.5% of New England's 2017 summer fuel mix to 56% in 2026.[38] Thus, the Commission should take seriously the need to ensure our electric grid is resilient to the various threats—both human and natural—that could have devastating consequences.

Several commenters contend that the Commission has already taken sufficient action by approving the Capacity Performance product in PJM and the pay-for-performance reforms to the ISO-New England capacity market.[39] Other commenters contend that the Eastern RTOs have large reserve margins, and suggest that these reserve margins resolve any concern about resilience.[40]

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[34] *Id.* at 7. *See also, e.g.,*, FirstEnergy Comments at 18-22; NEI Comments at 13-17; DOE Staff Report at 92-94.

[35] PSEG Comments at 2, 11-12.

[36] Reply Comments of Advanced Energy Management Alliance, Docket No. RM18-1 (Nov. 7, 2017) at 3.

[37] ISO-New England, *2017 Regional System Plan* at 65.

[38] *Id.* at 8.

[39] *See Comments* of LS Power Development on Notice of Proposed Rulemaking, Docket No. RM18-1 (Oct. 23, 2017), at 8-9, 11; Comments of Joint Consumer Advocates of the PJM Region, Docket No. RM18-1 (Oct. 23, 2017) ("PJM Joint Consumer Advocates Comments") at 13-18; PJM IMM Comments at 26-27; PA PUC at 15-19.

[40] *See* Comments of the Advanced, Renewable and Storage Energy Industry Associations at 12-13; Comments of the Midcontinent System Operator, Inc. at 12-13; Comments of the Pennsylvania Public Utilities Commission, Docket No. RM18-1 (Oct. 23, 2017) at 14; Joint Industry Comments

The Commission should reject these contentions, which erroneously conflate the concept of reliability with the concept of resilience. Existing capacity markets are targeted toward ensuring resource adequacy—in other words, that sufficient generation resources are available on the system to serve peak load in a wide range of operating conditions. The CP reforms were adopted to address a specific problem: although units had committed to provide capacity, they had not made the investments necessary to ensure that they were actually capable of operating during extreme and adverse weather conditions. The Commission adopted penalties for non-performance which were intended to incentivize the investments necessary to ensure unit performance.[41] This is certainly important, and, separate from its consideration of resilience, the Commission and PJM should evaluate whether the current penalty rate is high enough to provide the desired incentive.[42] Indeed, the first auction procuring only Capacity Performance resources has already been held, but clearing prices are too low to reflect investment by gas facilities in dual-fuel capability.

In all events, however, the CP and pay-for-performance reforms did not address the system-wide vulnerability to HILF events that results from the increasing interdependence of the gas and electric systems, which is aggravated by the retirement of fuel-secure resources like nuclear that do not rely on the gas supply system. To put it another way: the CP reforms focused on unit-level investments to improve unit-level performance, but did not address the system's increasing exposure to a common mode failure (such as an attack on the gas pipeline system) that would cause an entire class of generation of resources to fail simultaneously. Resiliency, in contrast to reliability, concerns this type of systemic threat. Making a system resilient to such threats ensures

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Opposing the DOE Proposal, Docket No. RM18-1 (Oct. 23, 2017) at 7; PJM Joint Consumer Advocates Comments at 4-5.

[41] *PJM Interconnection, L.L.C*, 151 FERC ¶ 61,208, at P 158 (2015).

[42] Exelon Comments at 31.

that the system is capable of "operating through, and recovering from a high-impact, low-frequency event" to the system as a whole.[43] Thus, as PJM recognizes, "a heavy reliance on one resource type … *could* raise questions about system resilience."[44]

For similar reasons, the Commission should find no comfort in the Eastern RTOs' large reserve margins. Of course, large reserve margins help support resource adequacy and help keep prices low for consumers. But the question is whether the reserves on the system are the right kind of resources to help sustain the grid in the event of a HILF event. Simply pointing to a large reserve margin fails to engage with that crucial question. The Commission has previously recognized as much. When approving ISO-NE's first winter reliability program, the Commission underscored the distinction between (on the one hand) resource adequacy and (on the other hand) resiliency against system-wide threats. The Commission explained: "[R]esource adequacy would be unlikely to reflect the unpredictability of fuel shortages and the likelihood that outage result from fuel shortages will simultaneously affect multiple resources."[45] Indeed, in markets where natural gas-based generators increasingly dominate, large reserve margins can provide a false sense of security, since the system's overdependence on just a few pipelines could make the system particularly vulnerable in the case of an attack.

Equally off the mark is the Rhodium Group's analysis, cited by various commenters.[46] According to the Rhodium Group, "[b]etween 2012 and 2016, there were roughly 3.4 billion customer-hours impacted by major electricity disruptions. Of that, 2,382 hours, or 0.00007% of

[43] PJM Comments at 18-19.

[44] *Id.* at 19.

[45] *ISO New England Inc.*, 147 FERC ¶ 61,026, at P 17 (2014).

[46] *See* Houser, Larsen, and Marsters, The Real Electricity Reliability Crisis (Oct. 3, 2017) available at http://rhg.com/notes/the-real-electricity-reliability-crisis.

the total, was due to fuel supply problems."[47] But that analysis, even if true, fails to appreciate the point of this proceeding. Experts are telling the Commission that there is a risk of a fuel supply disruption that could have disastrous consequences for our society. As Dr. Stockton describes in his comments, a HILF event that causes a cascading failure of the gas and electric infrastructure for a significant portion of the Nation's power grid for a prolonged period would have horrific consequences. Clean water would be unavailable and sewage systems would fail for weeks or months causing widespread risk of disease and ultimately jeopardize human lives. Food distribution would be sharply curtailed or stop entirely. Communication and transportation networks would collapse. Hospitals, nursing homes, and other medical facilities would lose their backup power and be unable to provide services to vulnerable members of the public.[48] Defense installations would gradually lose their ability to carry out their essential military function, making the nation significantly more vulnerable to attack from nation-state adversaries and terrorists and risking a collapse of law and order. It would be irresponsible to wait until after a HILF event has occurred to begin preparing for one. We have not experienced outages caused by massive cyber or physical attacks on the transmission and distribution system, either, but we still plan for them.[49]

Simply put, the Rhodium Group does not address the bulk power system's ability to withstand such an event. It does not even attempt to analyze, for example, what the consequences would be if the *single* gas pipeline serving more than 11,000 MW of generation in PJM were disrupted, let alone if multiple gas pipelines were disrupted. Nor does it assess the degree to which

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[47] *Id.*

[48] Stockton Initial Testimony at 9-10; Comments of Center for Security Policy, Docket No. RM18-1 (Oct. 23, 2017) at 1-2.

[49] *See, e.g.*, *Physical Security Reliability Standard,* 149 FERC ¶ 61,140, at P 18 (2014); *Revised Critical Infrastructure Protection Reliability Standards,* 154 FERC ¶ 61,037 (2106).

our vulnerability to such attacks would increase as the resource mix continues to move away from fuel-secure resources. Those who cite the Rhodium Group's elementary analysis as a reason for inaction would have the Commission wait for a catastrophe to happen before assessing whether something could have been done to address it.

2. The Fact That the Distribution and Transmission Systems Also Need Hardening Is No Reason for Inaction.

Some commenters argue that the Commission should ignore generation-related vulnerabilities because there are also transmission- and distribution-related vulnerabilities that need to be addressed. The fact that there are multiple vulnerabilities is no reason for inaction. The Commission does not need to choose between potential risks. It can and should address all system-level vulnerabilities that are capable of being addressed.

Indeed, it has already taken many steps to make the transmission system more resilient. For example, it directed NERC to address supply chain risks to certain cyber assets; it directed NERC to develop physical security standards in the wake of the April 2013 attack on the Metcalf Transmission Substation; and it directed NERC to develop standards governing planning and operations with respect to a 1-in-a-100-year solar storm. Stakeholders have also invested in making transmission and distribution systems more resilient. Utilities have increased acquisition of critical spare equipment.[50] Under the auspices of the Edison Electric Institute ("EEI"), utilities have instituted a Spare Transformer Equipment Program, and the industry is developing additional

[50] U.S. Department of Energy, Strategic Transformer Reserve Report to Congress at 6 (Mar. 2017) ("utilities report they are purchasing additional spares").

equipment sharing programs, including Grid Assurance[51] and RESTORE.[52] Utilities have also hardened transmission systems against adverse weather events and flooding, and they are investing in microgrids. NERC and stakeholders also conduct large-scale exercises and simulations to practice their response to various HILF-type events. [53]

All of these developments are valuable and should not only be encouraged, but also expanded. The Commission, RTOs, NERC, states, and industry more broadly should continue to assess the resiliency of the Nation's transmission and distribution system and make further policy changes as appropriate.

In tandem with those efforts, the Commission should *also* assess the resiliency of the generation fleet. In contrast with the transmission and distribution systems, where already much work has been done analyzing vulnerabilities and taking steps to address them, nothing has yet been done with respect to the risk to the generation fleet posed by HILF events.

The Commission is also uniquely positioned to address vulnerabilities arising from the generation fleet in the Eastern RTOs, in which states generally engage in little integrated resource planning and in which generation resources largely sell at wholesale. The Commission has all the authority it needs to ensure that generation owners and developers have the economic incentives to account for the impact of their investment decisions on system resiliency. In contrast, efforts to

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[51] *See* Grid Assurance, available at http://www.gridassurance.com/equipment-subscribers/.

[52] Utility Dive, *28 Utilities Join RESTORE Program to Boost Grid Resilience, Reliability* (Oct, 4, 2017), *available at*: https://www.utilitydive.com/news/28-utilities-join-restore-program-to-boost-grid-resilience-reliability/506400/.

[53] For example, NERC will be conducting GridEx IV, its biennial exercise, November 16-17, 2017. GridEx IV will allow utilities to demonstrate how they would respond to and recover from a simulated coordinated cyber and physical attack. *See* http://www.nerc.com/pa/CI/CIPOutreach/Documents/TLP_WHITE_GridEx%20IV%20Fact%20Sheet_20161202.docx.

enhance the resiliency of the transmission system and gas pipeline network by siting new transmission lines and pipelines, and to enhance the resiliency of local distribution networks, all require the involvement of other regulatory authorities.

3. Discussion of Costs and Benefits Is Premature.

Several commenters emphasize the costs of DOE's comprehensive cost-of-service proposal to ensure resilience. But their studies are silent on the potential benefits of addressing resilience, and policymakers must always consider costs and benefits together. In any event, it is premature to discuss costs and benefits. Exelon does not advocate immediately providing cost-of-service contracts to every coal and nuclear plant in the eastern RTOs. The Commission must first understand the scope and urgency of the Nation's vulnerabilities. Once the Commission has that data, it can establish a design basis threat and identify cost-effective solutions tailored to address it.

4. The Commission Cannot Afford to Delay Taking Action.

According to the PJM IMM, urgent Commission action to address the resiliency of the generation fleet is not necessary because nuclear plants are not actually under any economic distress and are not in danger of retirement. [54] The PJM IMM's analysis is deeply flawed. As discussed below and in the attached testimony from Michael Schnitzer (attached as Exhibit B), as few as 6% of nuclear units in PJM fully recover their avoidable costs.[55] Unless market conditions change, or these units are compensated for the resiliency they provide to the system, many nuclear units currently in operation are likely to retire in the coming years.

In contending otherwise, the PJM IMM attempts to compare the market revenues of these units—revenues earned from the markets for energy, ancillary services and capacity—to their

[54] PJM IMM Comments at 18, 20.

[55] Testimony of Michael Schnitzer, attached as Exhibit B, at 5 ("Schnitzer Testimony").

avoidable costs. He claims that these revenues are sufficient to cover costs and these units are actually profitable.[56] The PJM IMM's analysis is premised on a dramatic understatement of the costs nuclear units face, and, as a result, draws entirely the wrong conclusions. Mr. Schnitzer has corrected the improper omission of these costs, and the data demonstrate that most nuclear generators throughout PJM do not currently earn market revenues sufficient to cover their costs.[57] As a result, these units are at risk of retirement absent improvements to the market or other measures and the electric grid is at risk of losing the resiliency benefits these units provide.

There are two key flaws in the PJM IMM's analysis of costs. *First*, the PJM IMM excludes the on-going capital expenditures that nuclear units incur annually. This error is inexplicable. Nuclear units are complicated machines that are pervasively regulated. Every year, owners must invest significant amounts of capital to keep nuclear units operational and comply with their regulatory obligations. The PJM IMM's own sources clearly show these costs. He draws cost data from a recent report of the Nuclear Energy Institute ("NEI") outlining the average costs of nuclear units.[58] The NEI data clearly shows that these units have significant ongoing capital expenditures.[59] Obviously, these ongoing capital expenditures can be avoided by retiring a unit.

Indeed, the PJM IMM himself treats ongoing to-go nuclear capital expenditures as an avoidable cost when reviewing Avoidable Cost Rate calculations for nuclear units. And for good

[56] PJM IMM Comments at 18-20.

[57] Schnitzer Testimony at 5-11.

[58] Nuclear Energy Institute, *Nuclear Costs in Context*, August 2017, at 2-3, *available at* https://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Nuclear-Costs-in-Context.pdf?ext=.pdf

[59] *Id.*; Schnitzer Testimony at 6.

reason: the PJM tariff includes such capital expenditures as avoidable costs.[60] Yet the IMM inexplicably departs from that settled treatment of capital expenditures in his comments here.

The PJM IMM is aware that his analysis is deceptive, but the omission is buried in a footnote and justified with the following cursory explanation: "Capital expenditures are generally sunk costs and appropriately excluded from this analysis. To the extent that there are additional annual avoidable costs, the results could differ."[61] The first sentence of this footnote is false; the second sentence is a massive understatement. The NEI report shows that these expenditures are not "sunk." Because they occur predictably every year, owners of nuclear units can avoid them by retiring units. Retirement decisions are inherently forward-looking—resource owners must ask themselves: Will it be profitable for these units to continue to operate if current market conditions continue? In that context, using 2016 or 2015 revenues as a proxy for future revenues and comparing them to going forward costs, capital additions are clearly avoidable.[62] No reasonable business owner would disregard such foreseeable and sizeable costs. And when these costs are considered, the results *do* differ—dramatically. Including these costs increases the total cost of operating units by approximately one-third over the PJM IMM's estimates.[63]

Second, the PJM IMM disregards the market and operational risk associated with operating a nuclear unit, risks that can be avoided by retiring a unit.[64] For example, nuclear units face energy market risks resulting from unexpected forced outages. If an unexpected outage occurs, these units face a loss of revenue from the energy markets, as well as the need to purchase energy on the

[60] PJM Tariff, Att. DD § 6.8.

[61] PJM IMM Comments at 19, n.17.

[62] Schnitzer Testimony at 9-10.

[63] *Id.* at 6-7.

[64] *Id.* at 7-8.

market at a high spot price in order to cover a forward market sale. The costs of covering forward energy sales can be significant. For example, when Exelon's Calvert Cliffs plant experienced an unexpected five day outage in January 2014, Exelon was forced to cover the plant's forward energy sales at a significant loss with replacement energy purchases made from the real-time and day-ahead energy markets. The loss was equal to about 35 percent of the total capacity revenue for the year.

Units also face risks arising from energy price volatility. Market prices are unpredictable and, given the size of nuclear generators, the market for the energy is often not liquid at the point of sale. Congestion can arise on the system due to forced transmission outages or transmission maintenance and upgrades, which can significantly impact the energy price received. For example, during outages for construction at a substation in the western portion of the ComEd system in the Fall of 2016, Byron and Quad Cities saw significant increases in congestion cost, on some days exceeding $30/MWh.[65] Owners of nuclear units are required to self-insure against this risk and bear these costs. For baseload plants, which receive most of the revenue from the energy markets, the risk of energy price volatility can be particularly significant. A nuclear plant, for example, can expect to recover as much as 75 percent of its going-forward costs through energy market revenues. Thus, a ten percent drop in energy prices can require a 30 percent increase in the capacity revenues needed to cover going-forward costs. As this example demonstrates, volatile energy prices present

[65] Similarly, disturbances on the transmission system can cause generators to unexpectedly trip offline. *See* NERC, *Washington, DC, Area Low Voltage Disturbance Event of April 7, 2015* (Sept. 2015), *available at* http://www.nerc.com/pa/rrm/April%202015%20Washington%20DC%20Area%20LowVoltage%20Disturban/Washington_DC_Area_Low-Voltage_Disturbance_Event_of_April_7_2015_final.pdf (describing a low voltage transmission problem experienced in the Washington, DC area that caused several generators, including Calvert Cliffs, to trip).

a significant commercial risk, and this risk, too, must be considered when determining the capacity revenues needed to cover going-forward costs.

Exelon is not alone in noting the risks and attendant costs faced by nuclear units. In its comments in the Capacity Performance docket, Exelon proposed tariff language addressing the energy market risks faced by nuclear units.[66] In that docket, PJM explicitly supported Exelon's requested tariff clarifications, noting that "[g]iven the importance of these risk premiums to reasonably reflecting a seller's costs of committing as a Capacity Performance Resource, and the inherent challenges in quantify such risks, these are reasonable modifications."[67]

Other companies who actually own and operate nuclear generators agree with Exelon that these plants face significant economic challenges. FirstEnergy has stated that its three nuclear power stations "are all in danger of closing within the next two years due to economic reasons … [and that] '[o]ur plants have been losing money. We've continued to operate them at a loss. But at some point, those economics don't make sense.'"[68] PSEG likewise states, "Nuclear plants are being financially challenged by current and expected market conditions."[69]

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[66] *See* Motion to Submit Reply Comments and Reply Comments of Exelon Corp., Docket No. ER15-623-000 (Feb. 4, 2015) at 28-31 (proposing specific tariff language); Comments of Exelon Corp. Regarding PJM Interconnection, L.L.C.'s April 10, 2015 Response to the Commission's Deficiency Letter, Docket No. ER15-623-000 (Apr. 24, 2015) at 3-7 (reiterating tariff language).

[67] *See* Answer of PJM Interconnection, L.L.C., Docket No. ER15-623-000 (Feb. 13, 2015) at 89-90.

[68] FirstEnergy Comments at 24-25.

[69] PSEG Comments at 5; *see also* http://www.njspotlight.com/stories/17/10/31/pseg-backs-trump-administration-plan-to-spur-nuclear-industry/ (recent statements by Ralph Izzo); s*ee also Order Adopting A Clean Energy Standard*, Case Nos. 15-E-0302, 16-E-0270, 2016 WL 4129243, at *70 (N.Y. P.S.C. Aug. 1, 2017) (the New York State Public Service Commission analyzed the finances of the upstate New York nuclear plants in the course of approving the Zero Emissions Credit program, and made a determination that these units were financially distressed).

In sum, in recent years the majority of nuclear units in PJM have not earned sufficient market revenues to cover their avoidable costs, indicating that they are financially challenged and at risk of existing the market. For single unit nuclear generators, the PJM IMM estimates an average avoidable cost of $25.95/MWh. The cost of ongoing capital expenditures is $8.67/MWh and an appropriate measure of market and operational risk is $8.14/MWh, increasing the avoidable cost to $42.78/MWh. The costs from multi-unit sites similarly increases from the IMM's estimate of $18.73/MWh to $32.02/MWh.[70] Once the true costs of operating these units are accounted for, virtually all of the nuclear units in PJM are challenged and are at risk of retirement.[71]

II. The Commission Should Take Three Steps: Take Immediate Action to Ensure that the PJM Market Rules Do Not Cause Economic Stress to Fuel-Secure Resources, Gather and Assess Data from RTOs Regarding Bulk Power System Vulnerabilities, and Establish a Design Basis Threat That Can Serve as the Foundation for Specific Reforms.

The Commission should take a three-step approach to addressing the concern expressed by the Secretary, as described further below.

A. The Commission Should Take Immediate Action to Ensure That Unjust and Unreasonable Market Rules Do Not Send Inaccurate Prices Signals to Fuel-Secure Resources.

The Commission can take action in the immediate term to reduce the likelihood of further retirements by fuel-secure resources, while it gathers additional information regarding our vulnerabilities and considers how best to ensure generation resilience. *First*, the Commission should make clear that it will not mitigate the capacity market bids of fuel-secure units that receive state compensation intended to prevent their premature retirement. For example, New York and Illinois have adopted Zero Emissions Credit programs which place value on the carbon-free

[70] Schnitzer Testimony at 9.

[71] *Id.* at 9-10.

environmental attributes of nuclear generation, and focus their compensation on units whose attributes would be lost absent state support. Mitigating the capacity market bids of these units would undermine the state programs and run counter to the Secretary's goal of sustaining fuel-secure resources.

Second, Exelon endorses PJM's proposal for the Commission to create a pathway for PJM to correct a well-understood flaw in its energy markets that results in the systematic under compensation of units serving off-peak load.[72] Simply put, energy prices do not reflect the cost of producing power, as Michael Schnitzer explains in the attached testimony.[73] PJM's energy market has two stages. PJM first determines the security constrained economic commitment and dispatch for generation resources. That is, it decides which combination of units are able to serve load at the lowest cost. Next, PJM examines the dispatch and sets energy prices based on the short-run marginal cost of the units. To be economically efficient, energy prices must be set at a level that is consistent with the cost of the energy produced. In other words, prices should be set at a level sufficient to allow all generators that are operating to at least recover their variable costs, and the dispatch instruction for each generator should be profit-maximizing given the prices.[74]

PJM's current approach fails this test, as Mr. Schnitzer explains.[75] Baseload generators must often stay on overnight in order to meet load during peak hours. These generators cannot turn down below a certain level, but they are ineligible to set energy prices when operating at their minimum. As a result, energy prices during off-peak periods often do not reflect the production costs of generators operating during these periods, despite the fact that these generators are serving

[72] PJM Comments at 48.

[73] Schnitzer Testimony at 11-34.

[74] *Id.* at 15.

[75] *Id.* at 11-18, 25-30.

load and are part of the least-cost set of resources to do so. Instead, the energy price is set based on the short-run marginal cost of a different, cheaper unit. At night, these resources are sometimes wind units, which are willing to generate at very low or even negative LMPs in order to benefit from production tax credits; other times, they are the lowest cost combined-cycle gas units. At such times, the offers of these flexible units, rather than the cost of the baseload unit that is truly marginal, determines the locational marginal price. As a result, the baseload unit does not recover its costs, and energy prices do not reflect the true cost of serving load.[76]

Right now, PJM attempts to mitigate this problem through uplift to certain units. The self-scheduled coal and nuclear units needed for grid resiliency, though, are generally not eligible for uplift. Uplift also is not a long-term solution. As the Commission has repeatedly recognized, uplift payments should be reduced whenever possible. A central goal of the current price formation efforts is to move away from uplift as a solution to pricing errors. More fundamentally, these uplift payments undermine the notion of a single market-clearing price. Most generators receive one price—the market price—for the energy they produce. Certain generators, though, receive a different, higher price that is a combination of the market price and the uplift payment.[77]

This flaw in market design has severe consequences for nuclear units, which are always on and which typically self-schedule, so are ineligible to set price. At some times and in some locations, these nuclear units are the marginal resource, but LMP is set by flexible wind units willing to bid below zero. In these conditions, nuclear units are losing money every hour they operate, even though they are part of the least-cost set of resources needed to serve load. Even when LMPs are not negative, however, they are often lower than the marginal cost of serving load.

[76] *Id.* at 11-14.

[77] *Id.* at 14, 16.

For example, when a blockloaded coal plant is the marginal resource, it will not be allowed to set LMP, and so energy prices will be insufficient to support the dispatch.[78] Because nuclear units have very large fixed costs—higher fixed costs than they are able to recover from the capacity market—they depend upon energy margins in order to remain profitable.[79] When energy prices are lower than they ought to be, due to flawed price formation rules, nuclear units are no longer able to earn the revenues necessary to remain in operation.[80]

These nuclear resources are part of any reasonable least-cost portfolio over the long-run, particularly given their zero-emission characteristics, and any retirement of such a resource represents a permanent loss for customers and society at large. The units will not return and instead, they will be replaced by natural gas units that are, over the long term, more expensive. A system that already is over-dependent on natural gas will further lose resilient units and more gas-fired generation will be added to the system. Properly valuing the energy that these units produce thus not only will improve the efficiency and functioning of the market, but will also advance the Secretary's goal of preventing the further retirement of resilient resources.

PJM itself has recognized that this specific flaw in its approach to energy price formation is a problem that needs correction.[81] So too has the Commission. For inflexible peaking units, the Commission has declared market rules unjust and unreasonable in the Notice of Proposed

[78] *Id.* at 17-19.

[79] *Id.* at 6, 20-21.

[80] *Id.* at 17-19.

[81] PJM Comments at 43.

Rulemaking relating to fast-start pricing.[82] The Commission should make the same determination here.

To solve this problem in a manner consistent with principles of economics and good market design, PJM proposes to "relax" the price-setting constraints to better allow the costs of the power being produced to be reflected in the locational marginal price.[83] When an inflexible unit that is part of the least-cost set of resources is operating at its minimum, it will be allowed to set the energy market clearing price. This energy price formation proposal preserves the current security constrained economic dispatch and commitment. It simply sets prices in a manner that is consistent with actual operations—energy prices will reflect the true marginal costs of serving load. PJM's proposal will thus over time produce a lower-cost mix of resources that correctly balances low-cost baseload with more flexible (but usually more expensive) resources.

Additional work on this proposal still needs to be completed. In particular, certain committed units will be paid to ramp down to ensure that generation matches load.[84] Under the current approach to pricing, these units reduce their output in response to a lower energy price. Because energy prices will no longer be suppressed under the PJM proposal, these flexible units will need to receive an additional payment to follow the dispatch signal as large units become the marginal resource. The Commission should find the existing market rules unjust and unreasonable under Section 206, and direct PJM to adopt revisions within 90 days.

The PJM IMM has criticized these changes, even going as far as to suggest that PJM is proposing them to placate Exelon. The PJM IMM's unfortunate insinuation that PJM's integrity

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[82] *Fast-Start Pricing in Markets Offered by Regional Transmission Organizations and Independent System Operators*, 157 FERC ¶ 61,213 (2016).

[83] PJM Comments at 45.

[84] *Id.* at 39

and independence are in question is belied by a decade of academic commentary noting the very issue PJM has identified.[85] The reforms are supported not only by PJM, but also by many other economists and PJM stakeholders.[86] The weaknesses in the PJM IMM's technical objections, discussed further below, cannot be masked by taking a cheap shot at PJM.

The PJM IMM presents four major criticisms, each of which the Commission should dismiss.[87] First, he claims the proposal would raise costs to consumers without corresponding benefits. Second, he argues that the pricing change is not consistent with efficient dispatch. Third, he states that PJM's proposal inappropriately extends the theory behind the fast-start NOPR. Finally, he believes the proposal will have unintended consequences in the markets. The first three criticisms are not valid and the final one is premature.[88]

First, the concern about costs to consumers is both wrong and misses the point. Correcting the pricing error would produce long term savings by avoiding uneconomic retirement of units as well as incentivizing new, more efficient units to enter the market.[89] Additionally, because of their operational constraints, many units with long-lead times or high start-up costs cannot make commitment decisions within a 24-hour window. Because they cannot effectively participate in

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[85] William W. Hogan and Brendan J. Ring, *On Minimum-Uplift Pricing for Electricity Markets* (Mar. 19, 2003); Paul R. Gribik, William W. Hogan, and Susan L. Pope, *Market-Clearing Electricity Prices and Energy Uplift* (Dec. 31, 2007); Brendan J. Ring, "Dispatch Based Pricing in Decentralized Power Systems," Ph.D. thesis, Department of Management, University of Canterbury, Christchurch, New Zealand, 1995.

[86] *See, e.g.*, Initial Comments of the Electric Power Supply Association, Docket No. RM18-1 (Oct. 23, 2017) at 51-53; Comments of NRG at 4; Comments of PSEG at 25; Comments of Calpine at 22; *see also State Policies and Wholesale Markets Operated by ISO New England Inc., New York Independent System Operator, Inc., and PJM Interconnection, L.L.C.*, Docket No. AD17-11-000, Comments of Edison Electric Institute at 5-6.

[87] PJM IMM Comments at 36-37.

[88] Schnitzer Testimony at 22-23.

[89] *Id.*

the day-ahead market, they self-commit instead. These self-commitment decisions are made in light of the predicted energy price and, to the extent that the energy price is not set optimally, the decision to self-commit is also not optimal.[90]

Equally important, a cost/benefit framework is misplaced here. The Commission needs to determine whether the pricing model is just and reasonable. Because the current pricing structure does not support the actual cost of production, basic principles of good market design are violated.[91] Specifically, locational *marginal* pricing, the basic principle that underlies energy market pricing, is violated given that a number of resources that are operating are prohibited from setting the clearing price. Units that are needed are not covering their variable costs. In such a model, while low prices produce "savings" for consumers, those savings are generated by undercompensating units that are needed to serve load. This pricing model is not sustainable and consumers do not benefit in the long-term.

Second, the PJM IMM does not describe PJM's proposal correctly when claiming that it would be inconsistent with efficient dispatch.[92] Under the proposal, the dispatch of units in PJM would be the same as it is today.[93] But energy market prices would allow *all* units needed to serve load to cover their costs.[94] To be sure, higher prices will mean that flexible resources will have an incentive to increase their output, but these resources would receive an additional payment

[90] *Id.* at 23.

[91] *Id.* at 22.

[92] PJM IMM Comments at 39.

[93] Schnitzer Testimony at 23.

[94] *Id.* at 23-25.

designed to compensate it for the opportunity cost of following dispatch instructions.[95] This payment would resolve the incentive concerns raised by the PJM IMM.

Third, contrary to the PJM IMM"s assertions, PJM's proposal is also in fact a natural extension of the fast start NOPR.[96] PJM's energy market faces the same pricing problem whether the unit involved is a baseload inflexible unit or a fast-start inflexible unit. In either case, the relevant generator is part of a least-cost commitment and dispatch solution but it not permitted to set price. The LMP that results from the pricing run is not sufficient to cover the costs of the marginal unit and the pricing model does not support the dispatch. The same reasons that led the Commission to act under Section 206 in that rulemaking likewise warrant a finding here that PJM's energy pricing rules are no longer just and reasonable.

Fourth, the claim the proposal will produce unintended consequences is premature.[97] The PJM IMM claims that "no financial incentive supports the unit producing at the efficient dispatch level" and argues that resources will begin to self-commit at higher rates if the Commission approves the pricing proposal.[98] As PJM acknowledges, it will need to design an appropriate compensation mechanism to ensure that resources reduce their output in response to dispatch instructions. While this will be an important component of the proposal, it should be straightforward to design and mange. More fundamentally, this problem already exists in PJM. Without the current out-of-market payments to inflexible units, those units would not have the

[95] *Id.* at 24-25, 30-31.

[96] *Id.* at 25-30; PJM Comments at 44-46; *see also* Initial Post-Technical Conference Comments of PJM Interconnection, L.L.C., AD17-11, (June 22, 2017) at 4-5.

[97] Schnitzer Testimony at 32-33.

[98] PJM IMM Comments at 39.

appropriate incentives. PJM's proposal reduces this uplift and reduces the overall amount of out-of-market compensation needed to induce units to follow dispatch instructions. [99]

The argument that units will begin to self-commit inefficiently is also premature.[100] If designed correctly, self-commitment decisions will be improved. The core concept behind the proposal is that all units that are part of the least-cost solution should be permitted to set price, whether they are pool-scheduled or self-scheduled. Self-scheduled resources that are not part of the least-cost solution should not be allowed to set price. This approach should improve the incentives around self-commitment. Units that are part of a least-cost solution will have an incentive to self-commit when appropriate because they will be able to set price and recover their costs.[101]

* * *

Issuing a policy statement that fuel-secure units receiving state compensation will not have their capacity bids mitigated on account of that compensation, and fixing the well-understood flaw in PJM's energy markets, will not of course fully solve the problem of resilience. But these steps will improve the market's efficiency while also helping to prevent the further retirement of fuel-secure resources while FERC considers solutions more broadly targeted at resilience.

B. The Commission Must Gather Information from the Relevant RTOs That Will Enable It to Assess the System's Vulnerability.

In its initial comments in this docket, Exelon urged the Commission expeditiously to order the three eastern RTOs covered by DOE's NOPR to provide various critical pieces of information

[99] Schnitzer Testimony at 32-33.

[100] *Id.* at 33.

[101] *Id.* at 33.

about the current resiliency of the electric systems they administer.[102] Within 30 days, the RTOs should provide the Commission with a comprehensive inventory of all fuel supply for all generation within their footprint, by generator.[103] This information, which should not be difficult for the RTOs to gather, is necessary to allow the Commission to assess the fuel security within each RTO and the vulnerability of each individual generator to disruption should its fuel supply be cut off. Within 60 days, the RTOs should provide the Commission with a comprehensive fuel reliance analysis, detailing the consequences to load should the supply of particular types of fuel, or a combination of fuel types, be interrupted.[104] This analysis should be detailed, and include not only a discussion of how much load will be unserved, but also the financial and security impacts of prolonged blackouts.[105] In addition, given that natural gas-based generation is peculiarly vulnerable to common mode failures, the RTOs should analyze and report to the Commission on their ability to continue to serve load even in the event of a multi-pipeline outage, and the time it would take to repair a significant pipeline outage.[106] This body of information will allow the Commission to order the changes necessary to ensure that the organized markets can sustain whatever threats DOE and others identify in the design basis threat analysis Exelon believes must also be immediately undertaken.[107]

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[102] *See* Exelon Comments at 35-39.

[103] *Id.* at 36.

[104] *Id.*

[105] *Id.* at 37.

[106] *Id.*

[107] *Id.* at 39-41.

C. The Commission Should Work with Other Government Entities to Establish a Design Basis Threat.

Once the Commission receives the data from RTOs, it needs to be able to evaluate it. Right now, the Commission and the entities it regulates simply cannot assess the resilience of the electric grid against the threat of serious disruptions to the natural gas fuel supply. Because no description of the threat exists, the risk is uncertain and policy solutions are unclear. Exelon recommends that the Commission take action to remove this uncertainty by partnering with other federal agencies to develop a design basis threat. While DOE may be the appropriate agency to take the lead in developing a DBT, the Commission and other agencies have an important role to play.

As Dr. Paul Stockton outlined in his testimony attached to Exelon's initial comments and supplemented by additional testimony submitted with these reply comments (Exhibit A),[108] the DBT is a well-understood regulatory tool used by the Nuclear Regulatory Commission in order to provide guidance to owners of commercial nuclear generators. It identifies the threat to the units and allows owners of the units to develop strategies to mitigate the risk.[109] DBTs are also used by the Department of Homeland Security and the DOD to address threats to other critical infrastructure.[110]

A version of this model could serve a valuable purpose in guiding the analysis of the resilience of our power supply. Right now, RTOs and other entities are considering the risks of over-dependence on natural gas, but are doing so on their own. This approach means that the planning assumptions by these entities are not coordinated and are not necessarily consistent.

[108] Stockton Supplemental Testimony at 2.

[109] *Id.* at 7-8.

[110] *Id.*

Moreover, the lack of involvement from national security agencies limits the opportunities for intelligence-related input from the DOE and other partner federal agencies.[111]

DOE need not start from scratch to develop a DBT for fuel resilience. NERC and other entities have already produced studies that could serve as the foundation of such a DBT. Dr. Stockton identifies three studies from NERC that touch on issues relating to the proposed DBT. First, NERC conducted a joint analysis in 2010 with the DOE on high impact, low frequency events.[112] This study warned that coordinated attacks on multiple vulnerable points on the system are possible and could produce extended, widespread outages.[113] Next, NERC came to a similar conclusion in 2012 in its *Severe Impact Resilience* study and recognized the risk of coordinated attacks on the grid.[114] Finally, NERC focused specifically on the risks of a cyberattack and also emphasized the risks of system collapse and widespread blackouts.[115] These studies, as well as others,[116] show the feasibility of assessing these risks in a DBT.

As it develops such a DBT, the DOE should consider a range of risks to resiliency. Dr. Stockton recommends analyzing potential large scale disruptions to the gas supply. Both natural and manmade threats could cause such disruptions. [117] International actors, as well as terrorist groups, could conduct physical or cyberattacks that disable natural gas infrastructure needed to

[111] *Id.* at 8.

[112] *Id.* at 9.

[113] *Id.* at 10.

[114] *Id.*

[115] *Id.* at 11.

[116] *Id.*

[117] *Id.* at 12.

supply fuel for generation. Earthquakes and other natural disasters can have similar effects. Additionally, natural catastrophes could create weaknesses that can be exploited by adversaries.[118]

With a DBT in hand, the Commission will then be able to devise solutions that address the threat. In doing so, the Commission should not allow itself to be hide-bound by an ideological commitment to either markets or command-and-control regulation. It should offer RTOs the opportunity to propose market-based solutions, but should remain open to adopting non-market solutions if necessary. The Commission's ultimate priority must be to secure the Nation's electric grid—and to achieve that goal in the manner that is least burdensome to customers.

CONCLUSION

The deluge of comments the Commission has received in this docket is only further evidence, if any was needed, that the issue of grid resiliency is one of overarching importance, and that Commission action will have widespread consequences for the bulk power system and the nation as a whole. Exelon believes the Commission must expeditiously gather necessary information from the RTOs, and clearly define the resiliency threat it seeks to counter, before it develops a long-term solution. But these actions should not prevent the Commission from taking the immediate steps it can, today, to halt the retirements of baseload nuclear units that are among the most resilient in the generation fleet. The price formation proceedings already underway in PJM, and other state-based initiatives to support zero-emissions generators, are important steps towards that goal.

[118] *Id.* at 13.

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Respectfully submitted,

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EXELON'S ANSWERS TO SELECTED QUESTIONS POSED BY COMMISSION STAFF (OCT. 4, 2017)

Need for Reform

Question 1: *What is resilience, how is it measured, and how is it different from reliability? What levels of resilience and reliability are appropriate? How are reliability and resilience valued, or not valued, inside RTOs/ISOs? Do RTO/ISO energy and/or capacity markets properly value reliability and resilience? What resources can address reliability and resilience, and in what ways?*

Resiliency and reliability are fundamentally different concepts. Reliability concerns (1) resource adequacy, namely whether there exists sufficient generation resources to serve load at all times throughout a wide range of operating conditions; and (2) operational security, that is, the ability of the electric system to serve load notwithstanding disturbances. Resiliency, by contrast, refers to the system's ability to prepare for, absorb, and rapidly recover from high-impact, low-frequency or unknown-frequency ("HILF") events. Unlike traditional reliability events based upon weather or forced outage rates which can be probabilistically determined based upon historical data, a HILF event (for example, a cyber-attack by a nation-state or other malicious actor) may not be forecastable. For this reason, HILF events not only encompass incidents that are expected to occur infrequently, but also events that cannot be forecasted because of significant unknowns. Resilience also differs from reliability in having to account for the underlying nature of man-made threats, which differ from hurricanes and other familiar natural hazards. Unlike hurricanes, adversaries are intelligent and adaptable. Adversaries will also be able to selectively target points of special vulnerability in energy systems, including those related to fuel resilience and gas-electric system interdependencies. Initiatives to define the attributes of resilience and assess measures to strengthen them will need to incorporate these non-traditional risk factors.

The eastern RTO capacity markets generally value reliability by giving units a financial incentive to be capable of generating power whenever called upon. Because the capacity markets focus on unit level commitments, they do not account for "common mode failure"—that is, the risk that multiple units will fail due to a common cause external to the units, such as a gas supply interruption. Resiliency concerns systemic threats such as these. However, the RTOs/ISOs do not value a unit's contribution to system resiliency, and until this proceeding resiliency has not been a focus for either the organized markets or the Commission.

The Commission should take certain immediate steps to ensure that fuel-secure resources that contribute significantly to system resiliency are being appropriately compensated for the resiliency they provide. As Exelon, PJM, and others have explained in their comments, flaws in PJM's energy market design systematically undercompensate such units, exacerbating the economic pressures these units face and contributing to their retirements. The Commission should create a process for PJM to address this flaw in its energy market. The Commission should also gather information from RTOs to identify the bulk power system's vulnerabilities to HILF events. Using that information, the Commission should establish a design basis threat, which can serve as a reference point for the adoption of market reforms intended to value resiliency.

Question 2: *The proposed rule references the events of the 2014 Polar Vortex, citing the event as an example of the need for the proposed reform. Do commenters agree? Were the changes both operationally and to the RTO/ISO markets in response to these events effective in addressing issues identified during the 2014 Polar Vortex?*

The 2014 Polar Vortex was a significant event because it exposed serious reliability deficiencies within PJM and ISO-New England. Generators that had committed to perform during harsh winter weather were unable to perform, and their failure exposed the organized markets' failure to adequately incentivize generators to provide reliable service. PJM has not faced another weather event as extreme as the 2014 Polar Vortex, and so it is difficult to assess whether the Capacity Performance reforms have succeeded in incentivizing owners to make the investments necessary to ensure performance. Exelon continues to believe that the penalty rate in PJM for a generator's failure to perform remains too low, and, as a result, important investments have not been made. For example, capacity clearing prices have been too low to support the development of dual-fuel capability by gas-fired units.

In all events, however, the issues raised in this docket are quite different from those addressed by the Commission in the wake of the Polar Vortex. The Commission's focus post-Polar Vortex was on creating financial incentives that would lead unit owners to make investments in the performance of their units. This docket, by contrast, concerns systemic threats to the grid external to any particular unit—threats which could affect many units simultaneously. For example, the CP reforms were intended to incentivize owners of gas-fueled plants to enter firm fuel arrangements so their supply could not be curtailed during extreme cold weather. But the CP reforms were not intended to address the possibility that—notwithstanding firm supply arrangements—there might be a gas supply disruption due to a physical or cyber attack on key pipelines. Such a supply disruption would affect numerous units simultaneously. A resilient grid is one that can withstand that type of event.

Question 3: *The proposed rule also references the impacts of other extreme weather events, specifically hurricanes Irma, Harvey, Maria, and superstorm Sandy. Do commenters agree with the proposed rule's characterization of these events? For extreme events like hurricanes, earthquakes, terrorist attacks, or geomagnetic disturbances, what impact would the proposed rule have on the time required for system restoration, particularly if there is associated severe damage to the transmission or distribution system?*

Certainly some extreme weather events, earthquakes, terrorist attacks, or geomagnetic disturbances can properly be characterized as HILF events and are and should be the subject of resiliency planning. Exelon believes it is premature to settle on precise list of events that resiliency planning should address. Likewise, while it is commonly understood that nuclear units can significantly contribute to swift system restoration,[119] Exelon believes it is premature to

[119] Nuclear units are resilient during extreme weather conditions. During Hurricane Sandy, most of the nuclear units in the path of the storm stayed operational throughout the storm. Units that

settle on a particular "solution" to the problem. As Exelon indicated in its comments, the first critical step for the Commission is to work with DOE and others to establish a design basis threat that encapsulates the resiliency deficiencies that need to be addressed. Once this has occurred, the Commission should consider a variety of potential solutions and evaluate which ones will meet the design basis threat in the most cost-effective manner. The proposal in the NOPR may be part of the solution, but Exelon believes further analysis and study is required before that conclusion can be reached.

Question 4: *The proposed rule references the retirement of coal and nuclear resources and a concern from Congress about the potential further loss of valuable generation resources as a basis for action. What impact has the retirement of these resources had on reliability and resilience in RTOs/ISOs to date? What impact on reliability and resilience in RTOs/ISOs can be anticipated under current market constructs?*

As Exelon has noted in its comments, many experts – including NERC – have correctly concluded that retirements of resilient baseload generation is a serious problem. Increasing reliance on gas generation creates the danger that a common mode failure—such as a gas pipeline disruption—could wipe out a large quantity of generation all at once. Fuel-secure units such as nuclear stations provide a valuable hedge against that risk. Moreover, the retirement of a nuclear plant is irreversible. Once the resiliency benefits of these plants are lost, they cannot be regained. The Commission should direct RTOs to provide data to assess the impact that the retirement of these resources had had on reliability and resilience. In its comments, Exelon identified a number of categories of data that RTOs should be directed to provide to the Commission, so that the Commission can accurately assess what impact these retirements will likely have on resiliency and what reforms are needed.[120] ISO-NE likewise highlighted its concern about the disruption of the natural gas supply at the October 2017 Commission open meeting when it presented its Winter 2017-2018 Operations and Market Performance update. It noted that "the ability to meet energy needs is at risk if gas cannot be supplied to gas-fired generators."[121] ISO-NE repeated these concerns in its comments in this docket.[122]

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were required to shut down restarted quickly when the storm ended. Because such units are safely taken offline during an event, they can return to service quickly after an event to allow the grid to resume operation. That quality would be crucial in the face of a major disruption to the natural gas supply. *See* Nuclear Energy Institute, *Nuclear Energy Facilities Prove Resilience During Hurricane Sandy*, October 30, 2012, *available at* https://www.nei.org/News-Media/Media-Room/News-Releases/Nuclear-Energy-Facilities-Prove-Resilience-During

[120] Exelon Comments at 36-37.

[121] Presentation of ISO-NE, October 19, 2017, available at https://www.ferc.gov/CalendarFiles/20171019125657-6-ISONE.pdf

[122] Comments of ISO-NE at 8-9 ("ISO-NE is concerned about the region's gas dependence").

Question 5: *Is fuel diversity within a region or market itself important for resilience? If so, has the changing resource mix had a measurable impact on fuel diversity, or on resilience and reliability?*

There is no question that the changing resource mix has had a detrimental impact on the fuel diversity within RTOs/ISOs, and that declining fuel diversity in turn has made the system more susceptible to a common mode failure, such as a gas supply disruption. A diverse generation mix provides an extremely valuable hedge against that risk.

Other

Question 3: *Please describe any alternative approaches that could be taken to accomplish the stated goals of the proposed rule.*

As Exelon has noted in its comments, there are immediate steps the Commission should take to reduce the risk of further imminent retirements of nuclear resources and to gather the information needed to formulate comprehensive market reforms. These steps include: (1) providing a means for PJM to adopt energy market reforms intended to ensure that energy prices are sufficient to support dispatch; (2) issuing a policy statement declaring that nuclear units receiving compensation from state programs like the Illinois and New York Zero Emissions Credit programs, which have averted the retirement of nuclear resources, will not have their capacity market bids mitigated; (3) requiring RTOs/ISOs to submit information regarding their susceptibility to fuel-supply interruption and the potential impact of such interruption on the RTO/ISO's ability to serve load; and (4) establishing a design basis threat that can serve as a reference point for specific reforms.

Question 4: *What impact would the proposed rule have on consumers?*

As discussed in Dr. Stockton's testimony, the consequences to consumers of a black sky outage would be devastating. Preventing this by increasing the resiliency of the bulk power system is essential.

EXHIBIT A

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Grid Reliability and Resilience Pricing	**)** **)** **)**	**Docket No. RM18-1-000**

SUPPLEMENTAL TESTIMONY OF

DR. PAUL STOCKTON

ON BEHALF OF

EXELON CORPORATION

November 7, 2017

My name is Paul Stockton. I am the Managing Director of Sonecon, LLC, a security and economic advisory firm in Washington, D.C. I submitted initial testimony in this docket on behalf of Exelon outlining the risks to the resilience of fuel supplies for power generation, especially those related to natural gas, and proposed steps to mitigate those risks. This additional testimony is designed to expand on my earlier submission.

Bulk Power System (BPS) entities cannot adequately assess the resilience of their fuel supplies for power generation because they lack the necessary analytic framework. In particular, neither the Department of Energy (DOE) nor any other Federal agency has provided BPS entities with a description of the threat against which fuel resilience should be measured. Without the ability to anticipate the likely scope and severity of an attack on natural gas pipelines and other sources of fuel, the Federal Energy Regulatory Commission (FERC) and the entities it regulates cannot measure the adequacy of current fuel resilience measures, or evaluate the potential benefits of additional mitigation options.

In my initial testimony,[1] I recommended the establishment of a Design Basis Threat (DBT) to support such assessments. Government-vetted DBTs already provide descriptions of threats to other infrastructure sectors to help guide their evaluation of security requirements and mitigation measures. For example, the Nuclear Regulatory Commission (NRC) provides a DBT to owners of commercial nuclear generators to help them ensure the adequacy of their security measures against manmade threats. In this testimony, I examine how a DBT for fuel resilience might provide unique benefits for assessing the current status of that resilience, and for evaluating options to mitigate gaps that may emerge against increasingly severe threats. My

[1] Testimony of Paul Stockton at p. 4-5.

testimony presents three overall findings on why developing a DBT is so vital for addressing fuel resilience and recommendations on how that development process should go forward.

First, I explain the need for a DBT. Without a government-vetted DBT, RTOs and other BPS entities are left to develop their own characterizations of the threat, leading to disparate analytic frameworks for assessing the scale and potential impact of fuel interruptions.

Second, I recommend an approach to determine the threat characteristics that the DBT should comprise. The DBT established by the Nuclear Regulatory Commission for commercial nuclear power reactors provide a useful precedent and model for developing a DBT focused on fuel resilience. DBTs provided by the Department of Homeland Security (DHS), the Department of Defense (DOD), and other Federal departments and agencies provide additional models for consideration. However, a fuel resilience DBT would need to focus on specific threats of fuel supply interruption, including those related to gas-electric system interdependencies and the risks of cascading fuel-related infrastructure failures that adversaries could create. Those threat characterizations should also account for both natural and manmade hazards that could inflict the simultaneous disruption of multiple gas pipelines and other fuel supply systems in multi-state regions. Analytic efforts conducted by NERC, entities at the direction of the Electricity Subsector Coordinating Council (ESCC), and BPS entities can also help identify the key threat characteristics that the fuel resilience DBT should encompass.

Third, I discuss the path forward to develop a DBT for fuel resilience. One promising option would be for the Department of Energy to lead the development of the DBT, in close coordination with the Commission, other Federal departments and agencies, BPS entities, the ESCC, NERC, and additional stakeholders in grid resilience with expertise on emerging threats. Such a DBT could also be structured in a “tiered” fashion, with a baseline DBT provided to all

BPS entities at the level of "For Official Use Only" and supplementary DBTs provided as needed at higher levels of classification to cleared industry personnel.

I. The Need for a DBT

The Department of Energy's *Staff Report to the Secretary on Electricity Markets and Reliability* (August 2017) highlights the need to "develop policy metrics and tools for evaluating BPS-wide provision of resilience and considering all aspects of the electricity system that contribute to resilience," including fuel supply and storage, and other factors critical to grid reliability and resilience.[2]

A growing number of RTOs and other BPS entities are developing and applying such evaluative tools. In particular, these entities are either assessing or planning to assess potential risks to their fuel supplies, especially natural gas, and the potential impact of fuel interruptions on grid reliability. PJM, for example, has conducted pioneering studies of the potential risks created by increased reliance on natural gas, including in its *Natural Gas Contingency Scenario Analysis*.[3] These studies are essential to address the resilience challenges identified in the NOPR.

However, the DOE Staff Report also identifies a critical gap for conducting such assessments. The Report cites PJM's finding that "criteria for resilience are not explicitly defined or quantified today."[4] The Report goes on to recommend that "Each RTO/ISO should strive to explicitly define resilience on its system and conduct resource diversity assessments to more

[2] Department of Energy, *Staff Report to the Secretary on Electricity Markets and Reliability*, August 2017, p. 128.
[3] Transmission Expansion Advisory Committee, "Reliability Analysis Update," *PJM Interconnection*, September 14, 2017, http://pjm.com/-/media/committees-groups/committees/teac/20170914/20170914-reliability-analysis-updates.ashx.
[4] PJM Interconnection, *PJM's Evolving Resource Mix and System Reliability*, March 2017, p. 6.

fully understand the resilience of different resource portfolios. Federal, state, and local work to define and support system-wide resilience is also needed."[5]

Providing a DBT offers a uniquely valuable opportunity for such Federal support. The Federal government currently leaves RTOs and ISOs largely on their own to characterize threats to their fuel resilience. This approach is likely to produce disparate planning assumptions regarding the scale and severity of such threats. The government's "hands off" approach also limits opportunities for appropriate intelligence-related input from the Department of Energy and other Federal departments and agencies to support the development of a vetted, appropriately informed DBT. This lack of Federal support is especially notable given the risk that fuel supply interruptions could jeopardize the flow of power on which military bases and other national security assets depend. To help strengthen U.S. security, the Federal government should work with BPS entities and other resilience stakeholders to develop a vetted, intelligence-informed DBT for assessing and mitigating risks fuel resilience.

A DBT of this kind would also help RTO and ISO efforts to meet the underlying assessment problems posed by the proposed Rule. In commenting on the Rule, David Patton, Market Monitor for MISO, NYISO and ISO-NE, noted that "Without first identifying in detail the contingencies and associated reliability risks to the system, there is no way to quantify a resilience requirement."[6] Filling this gap with a DBT will be essential for establishing the objective, analytically sound assessment system needed to achieve the goals of the proposed

[5] Department of Energy, *Staff Report to the Secretary on Electricity Markets and Reliability*, August 2017, p. 128.
[6] Comments of Potomac Economics, Ltd., Docket No. RM18-1 (Oct. 20, 2017) at 5; Michael Kuser, Tom Kleckner, Rory D. Sweeney, Amanda Durish Cook, "RTOs Reject NOPR; Say Fuel Risks Exaggerated," *RTO Insider*, October 24, 2017, https://www.rtoinsider.com/market-monitor-nuclear-coal-nopr-iso-ne-78297/.

Rule. The need for a consistent, government-vetted DBT is further highlighted by the threat assumptions that undergird recent fuel resilience studies. While excellent as far as they go, these studies typically focus on assessing the consequences of the interruption of a single major gas pipeline. That is helpful but not sufficient. Any major power willing to accept the risks associated with attacking a single U.S. pipeline may well decide to strike on a much more massive scale, and seek to disrupt all flows of gas for power generation in a given RTO or ISO service area. Specifying the extent of such anticipated fuel interruptions will be essential to provide a foundation for assessing BPS fuel resilience, and for analyzing the cost-effectiveness of various options to mitigate the emerging threat.

II. Existing DBT Models and Special Requirements for a Fuel Resilience DBT

To accelerate the development of a DBT for fuel resilience, one promising approach would be to borrow from existing DBT models and adapt them to the special fuel-related challenges posed by catastrophic natural and manmade hazards. Most significantly, the NRC has created a DBT for nuclear power plants and related facilities.[7] The requirement to establish this DBT and the basic threats it should comprise are specified in the *Energy Policy Act* of 2005.[8] These threats include "multiple, coordinated groups of attackers, suicide attacks and cyber threats," as well as other potential attack vectors.[9]

[7] The NRC's DBT provide performance-based requirements which allow each facility to develop site-specific strategies. It applies to commercial nuclear power reactors and Category I Fuel Cycle Facilities. See: "Frequently Asked Questions About NRC's Design Basis Threat Final Rule," United States Nuclear Regulatory Commission, last updated August 11, 2017, https://www.nrc.gov/security/faq-dbtfr.html.
[8] 42 USC § 2210e (2005), https://www.ferc.gov/enforcement/enforce-res/EPAct2005.pdf.
[9] 10 CFR § 73.1 (2010), https://www.gpo.gov/fdsys/pkg/CFR-2010-title10-vol2/pdf/CFR-2010-title10-vol2-sec73-1.pdf.

The NRC also regularly reviews and revises the DBT to keep pace with evolving threats. In particular, the NRC monitors domestic and foreign threat intelligence in an attempt to stay ahead of potential adversaries, issues periodic threat advisories and annual reviews, and will use this information to update the DBT as required.[10] While the DBT focuses on manmade threats, the NRC also provides earthquake engineering criteria for nuclear power plants and other guidance related to natural hazards.[11]

The NRC DBT scheme offers valuable models for establishing a fuel resilience DBT. For example, given the evolving threat to gas pipelines and other fuel supplies, it will be essential that the fuel resilience DBT be periodically updated as well. The nuclear DBT also provides a model of the appropriate level of detail for characterizing key threat vectors in an unclassified manner. In addition, existing mechanisms for the Department of Energy to share classified information with BPS entities could also be used to supplement unclassified DBT descriptions. Finally, just as the NRC sets standards for both natural and manmade hazards, the fuel resilience DBT should as well.

Even when Congress has not established statutory requirements for DBTs, Federal departments have issued them to help strengthen resilience and security across a range of critical facilities and functions. For example, DOD provides DBTs to support anti-terrorism and force protection standards, and mitigation measures based on requirements generated internally by the Department.[12] DHS also provides a DBT that establishes "the type, composition, and capabilities

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[10] "Threat Assessment," *United States Nuclear Regulatory Commission*, last updated August 14, 2017, https://www.nrc.gov/security/domestic/phys-protect/threat.html.
[11] "Appendix S to Part 50—Earthquake Engineering Criteria for Nuclear Power Plants," *United States Nuclear Regulatory Commission*, last updated August 29, 2017, https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-apps.html.
[12] *See* Department of Defense, DOD Security Engineering Facilities Planning Manual, September 2008, https://www.wbdg.org/FFC/DOD/UFC/ufc_4_020_01_2008.pdf

of adversaries" who might threaten Federal facilities. DHS uses the best available intelligence information and other relevant sources of data to develop and maintain the DBT. The baseline DBT provided by DHS is designated For Official Use Only (FOUO). In addition, DHS provides supplementary information as needed on specific threats and mitigation options, including at higher levels of classification.[13] A similar tiered approach to provide both an FOUO DBT and other threat assessments at higher levels of classification (to be provided to cleared BPS personnel) might also offer a useful design model for a fuel resilience DBT.

While these models from other departments are useful, a fuel-oriented DBT will need to focus on a different set of resilience challenges and threat vectors than those for nuclear power plants or Federal facilities. NERC Reliability Standard TPL-001-4 provides a valuable starting point. TPL-001-4 directs Transmission planners to assess the impact of extreme events, and if the analysis determines that such events could cause cascading outages, the Transmission planner should evaluate possible actions to reduce their likelihood or mitigate the consequences and adverse impacts to reliability.[14] To ensure that those assessments account for the risks posed by increasing reliance on gas for power generation, NERC is now considering a recommendation that "NERC registered entities should consider the loss of key natural gas infrastructure in their planning studies."[15] A DBT for fuel resilience could provide valuable support for such analysis

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[13] See: Department of Homeland Security, *The Risk Management Process for Federal Facilities: An Interagency Security Committee Standard: 2nd Edition*, November 2016, https://www.dhs.gov/publication/isc-risk-management-process.

[14] *See* Requirements R 3.2 and R 3.5 of Standard TPL-001-4 – Transmission System Planning Requirements.

[15] Thomas Coleman, "Special Assessment: Potential Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System" (presentation at NERC Board of Trustees Meeting, New Orleans, LA November 9, 2017). http://www.nerc.com/gov/bot/Agenda%20highlights%20and%20Mintues%202013/Board_Presentations_November_2017.pdf.

by specifying the scope and severity of the gas infrastructure losses that entities should use in their studies.

However, no such DBT exists today. Only limited guidance exists on the scale and characteristics of the extreme events that should be used as a basis for assessing the impact of fuel system interruptions on grid reliability and resilience.[16] BPS entities would benefit from far more extensive support. In particular, using appropriate intelligence sources, it would be helpful if the Federal government could provide these entities with an assessment of the scale and nature of attacks that they must be prepared to confront. Such an assessment could also help entities account for specific risks to fuel resilience, including the risk that adversaries will target their attacks to exploit interdependencies between gas and electric infrastructure.

As a starting point to develop a Design Basis Threat for fuel resilience, NERC and other industry stakeholders have already produced studies that highlight key resilience challenges to address in such a DBT. In particular, three NERC studies have examined both the characteristics of natural and manmade hazards that could cause catastrophic outages, as well as possible mitigation measures to adopt against the risks they pose.[17] These and other studies are useful starting points, but also have gaps in terms of characterizing the threat to fuel supplies. Filling those gaps will be necessary for developing a fuel resilience DBT.

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[16] *See, e.g.*, NERC, *2016 Long-Term Reliability Assessment*, December 2016, p. 21. The assessment notes that "As part of future transmission and resource planning studies, planning entities will need to more fully understand how impacts to the natural gas transportation system can impact electric reliability."

[17] NERC noted that coordinated cyber or physical attacks "could damage or destroy key system components, significantly degrade system operating conditions, and, in extreme cases, result in prolonged outages to large parts of the system." See: NERC, *2015 Long Term Reliability Assessment*, December 2015, p. 27.

The first NERC study is a joint analysis with the Department of Energy to examine the risk of high impact, low frequency events. Particularly useful is the study's analysis of coordinated cyber/physical attacks to the BPS.[18] The report warns that coordinated cyber/physical attacks will purposefully target multiple vulnerable points on the system, and that sophisticated adversaries will adapt to protective measures to maximize disruptions. Such attacks "could result in long-term (irreparable) damage to key system components in multiple simultaneous or near-simultaneous strikes… quickly bring[ing] the system outside the protection provided by current planning and operating practices."[19]A coordinated cyber/physical attack, as described, would likely result in extended outages over a wide geographic area.

The second study examines severe disruptions to the BPS, and stems from the work of the *High Impact, Low Frequency* report. Much like that report, the *Severe Impact Resilience* study focuses primarily on coordinated cyber and physical attacks.[20] The study cautions that a coordinated physical attack on critical nodes in the grid can cause extensive damage to equipment that is difficult to replace, with significant impact to the system as a whole. Similarly, coordinated cyberattacks could cause simultaneous disruptions or misoperation that could be detrimental to system integrity.[21] While *Severe Impact Resilience* treats cyber and physical attacks as separate threats, a future Design Basis Threat should assume advanced adversaries will conduct attacks in both domains near-simultaneously.

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[18] The study also assesses the risks of pandemic illness and geomagnetic/electromagnetic disturbances. For more information, see: NERC and the Department of Energy, *High-Impact, Low-Frequency (HILF) Event Risk to the North American Bulk Power System*, June 2010.
[19] HILF Report, p. 26
[20] Like the *High Impact, Low Frequency* report, it also includes geomagnetic disturbances among the key threats for particularly severe events. See: NERC, *Severe Impact Resilience: Considerations and Recommendations*, May 2012, p. 1.
[21] NERC, *Severe Impact Resilience: Considerations and Recommendations*, May 2012, p. 1.

In a third study, NERC examined the cyberattack scenario in greater detail in a parallel effort from a cyber-focused task force. This study focuses on two primary attack vectors: 1) a coordinated attack which disables or impairs multiple control systems; and 2) intruders gaining control to purposefully misoperate the system, causing outages and/or damage. The potential ramifications are severe. If successful, adversaries could inflict losses of load and generation that cause system instability, and, ultimately, system collapse and widespread blackouts.[22]

Other industry initiatives could also be leveraged to create a DBT for fuel resilience. For example, NERC Standard CIP-014-2, *Physical Security*, provides a methodology for Transmission owners and operators to conduct their own assessment of potential physical threats and vulnerabilities.[23] NERC's *Geomagnetic Disturbance Planning Guide* provides yet another approach to assessing potential threats and system design requirements.[24] While neither of these guiding documents establishes a Design Basis Threat, they do provide useful methodological approaches that might be valuable in developing a DBT for fuel resilience.

The Department of Energy has also sponsored a study by ICF International to establish a 'baseline' of adversarial threats to the North American electric grid. The report provides an in-depth examination of an array of physical and cyber threats, including combined cyber-physical events.[25]

However, none of these studies provides a detailed analysis of the fuel resilience challenges identified in the NOPR. Nor are any of them adequate to capture the risks created by

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[22] NERC, *Cyber Attack Task Force: Final Report*, May 2012, p. 2.
[23] *See* NERC Standard CIP-014-2, *Physical Security*, May 2015, http://www.nerc.com/_layouts/PrintStandard.aspx?standardnumber=CIP-014-2&title=Physical%20Security&jurisdiction=United%20States.
[24] NERC, *Geomagnetic Disturbance Planning Guide*, December 2013, p. 9.
[25] ICF International, *Electric Grid Security and Resilience: Establishing a Baseline for Adversarial Threats*, June 2016, p. 19.

gas-electric interdependencies, common failure modes,[26] duel-fuel resupply challenges and other threats I examined in my previous testimony. The threat of common failure modes is particularly concerning, as an increasing number of gas generators depend on a limited number of pipelines to deliver fuel required for power generation. Pipeline disruptions that lead to a shortage and/or outage of natural gas could therefore incapacitate multiple generators at the same time, increasing the scope and severity of the resulting power outages A single attack vector (especially via cyber means) could enable the adversary to disrupt fuel supplies for power generation across major portions of the United States. A DBT that can help BPS entities assess resilience against these threats will need to go far beyond any previous study of interruption scenarios.

As I outlined in my original testimony, the DBT should study both natural and manmade risks the system. Manmade risks could include threats from international actors, such as Russia or China, as well as terrorist organizations. The DBT should account for both physical and cybersecurity risks. For physical attacks, the DBT should encompass both familiar attack vectors as well as threats emerging from new technologies, such as unmanned aerial vehicles carrying advanced payloads. Finally, the DBT should account for the possibility that adversaries will combine cyber and physical attacks to create especially significant challenges to fuel supply systems.

[26] NERC will be presenting a Special Assessment: Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System to its Board for approval on Nov. 9, 2017. *See* Item 8c, Agenda, Board of Trustees, Nov. 9, 2017; Special Assessment: Potential Bulk Power System Impacts Due to Severe Disruptions on the Natural Gas System, Preliminary Findings, Board of Trustees, Nov. 9, 2017, located at http://www.nerc.com/gov/bot/Agenda%20highlights%20and%20Mintues%202013/Board_Presentations_November_2017.pdf.

Catastrophic earthquakes and other natural hazards can also inflict catastrophic damage on fuel infrastructure. Accordingly, I recommend that the DBT include both manmade and natural hazards. Given the importance of dual fuel generators as an option to mitigate the risks posed by gas system disruptions, I also propose that planners include contingency analysis of severe disruptions in secondary fuel supplies for dual fuel generators, and disruption of fuel resupply for backup power generators that serve critical natural gas compression stations and other key gathering and Transmission infrastructure. Finally, planners should conduct sensitivity analysis on the degree to which retaining a mix of fuel-resilient generation assets, including nuclear assets, can help reinforce the resilience of the BPS as a whole.

III. The Path to a Fuel Resilience DBT

Developing a DBT will require the input of multiple stakeholders. I recommend the Department of Energy lead a multistage effort in consultation with the Commission and other grid resilience stakeholders. As the Sector-Specific Agency (SSA) for the energy sector, including both the electricity and oil and natural gas (ONG) subsectors, DOE is especially well positioned to serve as the government lead for this effort. Close coordination with other Federal departments and agencies will also be required, especially those with: 1) SSA responsibilities concerning specific fuel supplies; and 2) information on the evolving threat that could supplement DOE's own extensive expertise. The ESCC, NERC, BPS asset owners and operators, and other resilience stakeholders could also play valuable roles in guiding this process.

Most important, close coordination will also be required with BPS entities to ensure that the DBT incorporates their own analytic priorities and requirements for support. The ESCC and other appropriate entities might support this BPS engagement process as well.

Given the increasing severity of threats to fuel resilience and the need for timely assessments of those challenges, I also recommend that the development of the DBT go forward in a phased process. DOE might first bring stakeholders together to produce a rapidly-available, top-level assessment of threat vectors and characteristics, equivalent to that which the NRC provides to the nuclear fleet in its publicly-available DBT descriptions. For example, this basic DBT could specify the percentage of gas pipelines that BPS entities should assume will be disrupted (and for how long). Follow-on DBTs could then address the more detailed challenges raised by gas-electric interdependencies and the threat vectors by which adversaries may seek to exploit them.

I also recommend that the fuel resilience DBT be structured in a "tiered" fashion, with a baseline DBT provided to BPS entities at the level of "For Official Use Only" and supplementary DBTs provided as needed at higher levels of classification to cleared industry personnel.

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Grid Reliability and Resilience Pricing	)	**Docket No. RM18-1-000**

DECLARATION OF PAUL STOCKTON

I declare, under penalty of perjury, that the foregoing Supplemental Testimony is true and correct.

Executed: November 7, 2017

Washington, DC

Paul Stockton

EXHIBIT B

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Grid Reliability and Resilience Pricing	)	Docket No. RM18-1-000

PREPARED TESTIMONY OF MICHAEL M. SCHNITZER

ON BEHALF OF EXELON CORPORATION

I. INTRODUCTION AND SUMMARY OF CONCLUSIONS

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS

A. My name is Michael M. Schnitzer. My business address is 30 Monument Square, Concord MA 01742.

Q. MR. SCHNITZER, BY WHOM ARE YOU EMPLOYED AND IN WHAT POSITION?

A. I am a Director of The NorthBridge Group, Inc. ("NorthBridge"). NorthBridge is a consulting firm that provides economic and strategic advice to the electric and natural gas industries.

Q. PLEASE DESCRIBE YOUR PROFESSIONAL QUALIFICATIONS AND EMPLOYMENT EXPERIENCE

A. In 1992, I co-founded NorthBridge. Before that, I was a Managing Director of Putnam, Hayes & Bartlett, which I joined in 1979. I have experience working with private sector

clients in the electric utility, natural gas, and private power industries, as well as with public and nonprofit agencies. My electric industry work has focused on regulatory policy, finance, and market structure issues.

I have testified before the Commission on a number of matters, and have participated in Commission technical conferences and workshops on capacity market and energy market design issues. I have also testified before the public utility commissions of Arkansas, California, Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Mexico, New Orleans, New York, Ohio, Pennsylvania, Rhode Island, Texas, Vermont, and Wisconsin.

Q. WHO IS SPONSORING YOUR TESTIMONY?

A. My testimony is sponsored by Exelon Corporation ("Exelon" or "the Company").

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. On October 23, 2016, the PJM Independent Market Monitor (IMM), Dr. Joseph Bowring, filed extensive comments in this docket on several topics related to the DOE NOPR.[1] The IMM's comments included an analysis that purports to address the economics of nuclear plants in PJM[2] as well as a multi-paged critique of an energy price formation "white paper" published by PJM in June of this year.[3] The IMM concludes that the

[1] Comments of the Independent Market Monitor for PJM, October 23, 2017. ("IMM Comments")
[2] *Ibid.* at 18-20.
[3] *Ibid.* at 34-41. Also see PJM Interconnection LLC, "Energy Price Formation and Valuing Flexibility," June 15, 2017 (the "PJM White Paper").

overwhelming majority of nuclear units have been able to recover their going-forward costs of operation from market revenues in each of the last two years. The IMM further concludes that the price formation proposal outlined in the PJM white paper is unnecessary and counter-productive, and that the existing market is functioning well.

The purpose of my testimony is to respond to the IMM's analysis and critique and explain the errors contained therein. With respect to the IMM's analysis of nuclear plant economics, I correct several fundamental errors in the analysis and explain why the IMM's conclusions are incorrect. With respect to the IMM's criticism of PJM's energy price formation proposal, I first explain why, contrary to the IMM's conclusion, the current energy pricing approach in PJM is flawed and results in both efficiency losses and discrimination. I then explain why the central feature of PJM's proposal that the IMM appears to find so objectionable – separate pricing and dispatch solutions - can address both the efficiency and discrimination problems with the current approach.

Q. COULD YOU PLEASE SUMMARIZE YOUR CONCLUSIONS?

A. Yes. First, the IMM's conclusion that the overwhelming majority of nuclear units have been able to recover their costs in the last two years is not correct. The IMM's analysis erroneously omits two categories of costs that should have been included: going-forward capital expenditures as well as the cost of certain operating and market risks that are borne by owners/operators of nuclear units. When these components of going-forward cost are included, the data from the last two years indicate that the

overwhelming majority of nuclear units have failed to cover their costs and are at risk of retirement – the exact opposite of the IMM's conclusion.

Second, as to energy price formation, the IMM's conclusion rests on the false premise that the current market dispatch solution produces the least cost dispatch and prices that are consistent with that solution. It does not. While the current market dispatch solution can produce a least cost physical commitment and dispatch in the short-term (assuming the level of self-commitment is economic), the resulting prices are not necessarily consistent with that physical solution. As a result, the prices from the current market dispatch solution cannot be said to be efficient, which means they do not promote either economic retention or entry. The current prices are also discriminatory in that certain resources are paid a higher energy price than other resources. The price formation approach that PJM described in its October 23 comments is designed to address the flaws in the current pricing rules and to produce prices that support economic commitment and dispatch of generation. Given the number of nuclear units that are at risk of retirement due, in large part, to insufficient energy margins, the PJM proposal should be brought before the Commission without delay.

II. CONTRARY TO THE IMM'S ASSERTION, THE OVERWHELMING MAJORITY OF PJM NUCLEAR UNITS HAVE FAILED TO RECOVER THEIR COSTS IN RECENT YEARS AND ARE AT RISK OF RETIREMENT

Q. PLEASE SUMMARIZE THE IMM'S CONCLUSIONS WITH RESPECT TO THE FINANCIAL VIABILITY OF PJM NUCLEAR PLANTS.

A. The IMM concludes that 90 and 74 percent of all nuclear units in PJM fully recovered avoidable (or going-forward) costs in 2015 and 2016 respectively and then goes on to claim that "there are very few nuclear units in PJM that are at risk [of retirement]."[4]

Q. DO YOU AGREE WITH THE IMM'S CONCLUSIONS?

A. No.

Q. WHY NOT?

A. The IMM's analysis significantly under-states nuclear going-forward costs. When properly analyzed, the same data relied on by the IMM indicate that as few as 6 percent of PJM nuclear units fully recovered going-forward costs in 2016 and therefore many units are at risk of retirement.

Q. HOW DOES THE IMM UNDERSTATE GOING-FORWARD COSTS?

[4] *Ibid.* at 18 and 20.

A. The IMM assumes that nuclear going-forward costs (excluding fuel) are $25.83/MWh for single-unit sites and $18.73/MWh for multi-unit sites, based on national average actual cost data for 2016 published by the Nuclear Energy Institute ("NEI").[5] These values correspond to the operating cost for nuclear generators in 2016, but completely exclude two additional components of going-forward cost: ongoing capital expenditures and compensation for operational and market risk.

With regard to ongoing capital expenditures, the same NEI data indicate that in addition to operating costs, nuclear generators also incurred annual ongoing capital expenditure costs of $8.67/MWh and $6.15/MWh for single- and multi-unit sites respectively in 2016. Excluding these costs is not appropriate. These additional costs are avoidable if a nuclear unit retires. The capital costs reported by NEI do not represent recovery of sunk capital expenditures incurred in prior years. Rather, they are capital expenditures incurred in the present year. Further, the data demonstrate that these expenditures are ongoing and significant in every year tracked, and can be expected to continue at a similar level going out into the future.[6] Ongoing capital expenditures are critical to maintaining the operating condition of nuclear plants; the industry consistently incurs these capital investments, year in and year out, to maintain safe, reliable operations.

[5] Nuclear Energy Institute, "Nuclear Costs in Context," at 2 ("NEI"). Attached as Exhibit A. The IMM includes fuel in his analysis as an offset to revenue, rather than as a component of avoidable cost (*see* IMM comments, footnote 16). The IMM does not provide his estimate of fuel costs. In correcting the IMM analysis, I utilized the fuel costs published by NEI ($6.77 and $6.75/MWh for single- and multi-unit sites, respectively).
[6] NEI at 3.

Thus, ongoing capital expenditures would be avoided if the plant were to retire and are an appropriate component of going-forward costs.

Q. WHY DID THE IMM EXCLUDE THESE COSTS?

A. In a footnote, the IMM observes that, in an operating year, these capital additions are largely sunk costs, and therefore should not be treated as going forward costs.[7] That explanation completely misses the point. Retirement decisions are inherently forward-looking decisions, not backward-looking. If the IMM's analysis is to have any value, it is to provide an answer to the following question: if nuclear owners think that future market conditions will be similar to 2016 (or 2015), will it be profitable for them to continue to operate? In that context, using 2016 or 2015 revenues as a proxy for future revenues and comparing them to going forward costs, capital additions are clearly avoidable. My corrected analysis provides the correct answer to the question, which is "no". Unless market revenues increase relative to 2016 levels, it will not be profitable to continue to operate a large fraction of the PJM nuclear fleet. The retirement risk is real.

Q. WHAT RISKS ARE BORNE BY OWNERS OF OPERATING NUCLEAR PLANTS?

A. Nuclear plant owners incur significant operational and market risks in continuing to operate merchant nuclear plants. These risks include the risk of higher-than-expected operating costs, lower-than-expected production due to outages, the risk of needing to cover liquidated damages forward sales at a very high spot price in the event of a forced

[7] IMM Comments at footnote 17.

outage, the risk of higher-than-expected performance penalties when serving as a capacity resource in PJM's recently-reformed capacity market, and the ongoing market risk of lower-than-expected forward and spot sales prices for energy and capacity. These ongoing risks make owning and operating a nuclear plant on simply a cash breakeven basis an untenable proposition for investors. Rather, on an ongoing basis, investors will require that plant owners either realize compensation for these risks above simple ongoing avoidable cash costs or avoid these risks by retiring the plant. Exelon has in previous proceedings supported an overall level of operational and risk compensation equal to ten percent of operating costs, capital expenditures, and fuel costs plus four dollars per megawatt-hour.[8] I adopt this value in correcting the IMM's analysis and show the range of nuclear profitability between simple breakeven versus cash going-forward costs only, and the same with this measure of risk compensation included as well.

My corrections to the IMM's nuclear going-forward cost information are summarized below:

[8] New York Department of Public Service Case 15-E-0302, Comments of Constellation Energy Nuclear Group LLC Concerning Staff White Paper on Clean Energy Standard, April 22, 2016, at 19-28.

($/MWh)	Single-Unit Sites	Multi-Unit Sites
Operating Cost (per NEI)	$25.95	$18.73
IMM estimate of Going-Forward Cost[9]	$25.83	$18.73
Plus Correction to Operating Cost[10]	$0.12	--
Plus Ongoing Capital Expenditures (per NEI)[11]	$8.67	$6.15
Corrected Going-Forward Cost without Risk	$34.62	$24.88
Plus Market and Operational Risk[12]	$8.14	$7.16
Corrected Going-Forward Cost with Risk	$42.78	$32.02

With corrections, the appropriate going-forward cost for a single-unit site is between $34.62 and $42.78/MWh, rather than $25.83/MWh (excluding fuel) and between $24.88 and $32.02/MWh for a multi-unit site, rather than $18.73/MWh (also excluding fuel).

Q. HOW DOES THE UNDERSTATEMENT OF GOING-FORWARD COSTS AFFECT THE RESULTS OF THE IMM'S NUCLEAR FINANCIAL VIABILITY ANALYSIS?

A. The IMM's analysis of the economics of PJM nuclear generators rests on a comparison of the market revenues of these units to their going-forward costs. Because going-forward costs are greatly understated, the extent to which nuclear market revenues exceed going-forward costs is dramatically overstated. The IMM's comments presents data that purport to show that 90 percent of PJM nuclear units covered their going-forward costs in 2015 and 74 percent covered their going-forward costs in 2016. When the same analysis is performed using corrected going-forward costs, including ongoing

[9] IMM Comments at 18.
[10] The IMM miss-states the operating cost of Single Unit Sites published in the NEI data. The actual published cost is $25.95/MWh, rather than $25.83/MWh. *See* NEI at 2.
[11] NEI at 2.
[12] Market and operational risk equal to 10% of total cost (including fuel) plus $4/MWh.

capital expenditures and market and operational risk, only 19 and 6 percent of PJM nuclear units covered their going-forward costs in 2015[13] and 2016 respectively when risk compensation is included as a going-forward cost. Even without including any risk compensation in going forward costs, only 61 and 32 percent of PJM nuclear units covered their cash going-forward costs in the same years.

	Percent of Nuclear Units with Full Avoidable Cost Recovery from All Markets[14]	
	2015	2016
IMM Analysis[15]	90%	74%
Corrected Analysis excluding risk compensation	61%	32%
Corrected Analysis including risk compensation	19%	6%

Q. WHAT CONCLUSIONS DO YOU DRAW WITH RESPECT TO NUCLEAR FINANCIAL VIABILITY IN PJM FROM THIS ANALYSIS?

A. The corrected analysis does not support the conclusion reached by the IMM; rather it supports the opposite conclusion. Virtually all of PJM nuclear units are financially-challenged and therefore many are at risk of retirement. Energy margins, the principal source of going forward cost recovery for nuclear plants, have fallen to a level which is not adequate for many units. This underscores the urgency of addressing flaws in

[13] For the 2015 analysis, I used single- and multi-unit nuclear avoidable costs from NEI's earlier report on 2015 nuclear costs. *See* Nuclear Energy Institute, Nuclear Costs in Context, April 2016, at 2.

[14] In calculating the percentage of nuclear units covering their avoidable costs from all markets, I estimated energy revenues based on unit-level day-ahead locational marginal prices for the relevant year, capacity revenues based on actual cleared RPM capacity prices for the relevant years and I further assumed that all nuclear units cleared as Capacity Performance resources in the relevant CP transition auctions. I assumed that nuclear units did not earn any ancillary services revenues. For each year, I compared these revenue estimates to the appropriate measure of going-forward costs.

[15] Extracted from IMM Comments, Table 9.

energy price formation in PJM which contribute to nuclear unit financial stress, which I discuss in the next section of my testimony.

III. PJM's CURRENT MARKET DISPATCH SOLUTION DOES NOT PRODUCE PRICES THAT ARE CONSISTENT WITH THAT SOLUTION.

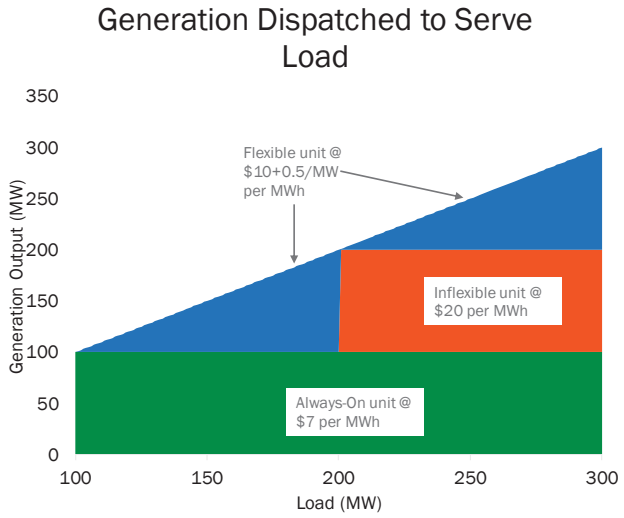
Q. PLEASE EXPLAIN WHY YOU DISAGREE WITH THE IMM ABOUT WHETHER THE CURRENT SYSTEM PRODUCES PRICES CONSISTENT WITH THE DISPATCH SOLUTION.

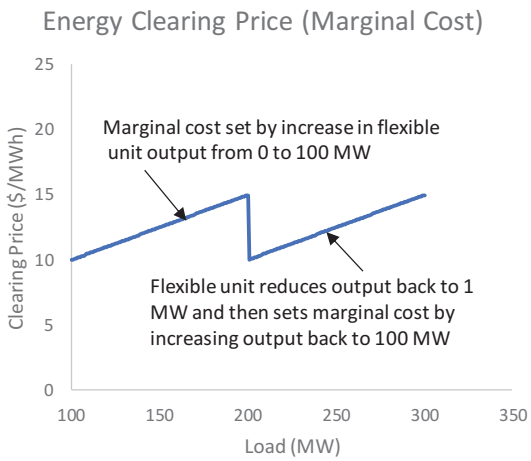
A. As I stated above, the contention that the current PJM market dispatch solution produces the least cost dispatch and prices that are consistent with that solution is central to the IMM's argument.[16] In effect, the IMM is arguing that the current system is not broken, and therefore does not need to be fixed. But a simple example illustrates that this is not the case, and that under the current system, prices are not always consistent with the dispatch.

Consider an electricity market with three generators: the first must always operate at a fixed output level of 100 MW and costs $7/MWh to operate (the "always-on unit"), the second can be either committed or offline but if committed must operate at a fixed level of 100 MW with variable costs of $20/MWh (the "inflexible unit"), and the third that can flexibly produce between 1 MW and 100 MW of output with an incremental cost of $10/MWh plus $0.05/MWh for each incremental MW of output (the "flexible unit").

[16] IMM Comments at 37.

The figures below show the economic dispatch solution at loads between 100 and 300 MW, and the associated energy clearing price under the current pricing regime.





As the dispatch chart illustrates, the least cost dispatch solution is to rely on the always-on and flexible units until load reaches 200 MW, to "back down" the flexible unit to 1 MW and bring on the inflexible unit when load is 201 MW, and then ramp the flexible unit back up as load increases from 201 to 300 MW.

What about the prices? As the price chart shows, energy prices increase and then decrease, and then increase again. From 100 to 200 MW the system marginal cost is defined by the marginal cost of the flexible unit and increases from $10 to $15/MWh. At 201 MW, the inflexible unit is committed but does not set the system marginal cost at that point. This is because, under PJM's current pricing methodology, the system marginal cost is set by the lowest-cost available source of incremental supply than can expand output in the very short term to supply an infinitesimal increase in demand.

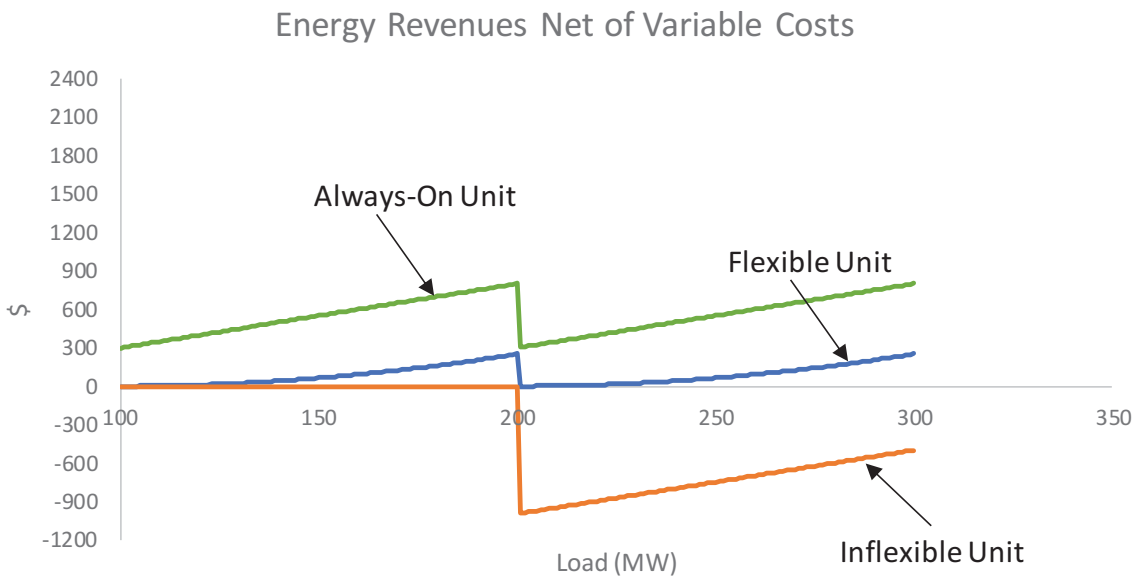
Thus, at 201 MW the inflexible unit is online at a fixed output level and cannot further increase output to supply any further increase in demand, however small, and the system marginal cost is set instead by the flexible unit at an output level of 1 MW, or $10/MWh. Thus, the system marginal cost (and energy clearing price) falls from $15/MWh at 200 MW of load to $10/MWh at 201 MW of load notwithstanding an increase in load. Basic micro-economic theory is based on the assumption that marginal supply costs increase as demand grows. But, as I will discuss in more detail below, electricity supply is different because of what economists refer to as a non-convexity, where the incremental cost of production is not continuously increasing with demand.[17] The failure of the existing pricing methodology to account for non-convexity causes a pricing anomaly where the clearing price goes down as demand increases. In my example, at load levels from 201 MW to 299 MW, the current PJM pricing methodology produces an anomaly where prices are not consistent with the physical dispatch.

Q. HOW DOES THIS ANOMALY IMPACT THE ABILITY OF DISPATCHED UNITS TO RECOVER THEIR VARIABLE COSTS?

A. The chart below shows the energy margin (energy revenues net of variable costs) of each of the generators at each load level. While the always-on and flexible units earn a positive energy margin at every load level, the inflexible unit is unable to cover its variable costs at every load level at which it is committed. Thus, at load levels up to 200

[17] *See* e.g., Richard P. O'Neill, Paul M. Sotkiewicz, Benjamin F. Hobbs, Michael H. Rothkopf, William R. Stewart, Jr., "Efficient Market-Clearing Prices in Markets with Nonconvexities," December 9, 2002.

MW, the energy prices are consistent with the dispatch. But, above 200 MW, the prices do not support the economic dispatch.



Recognizing that a generator cannot be compelled to operate at a loss, under the current system, PJM "solves" the pricing problem with an out of market uplift payment to the inflexible generator that offsets the losses it would sustain if it only received the prevailing market price. In the example, the uplift payment to the inflexible generator would result in it effectively receiving a price of $20 per MWh, split between the prevailing energy price of between $10 and $15 per MWh and whatever additional compensation is needed to move the compensation to the unit's breakeven point of $20 per MWh. But there are two problems with this solution: it does not produce "efficient" market clearing prices, and it is discriminatory.

Q. WHY ARE THESE PRICES NOT "EFFICIENT"? AND SHOULD THE COMMISSION BE CONCERNED?

A. In competitive markets, efficient prices are those that promote both productive and allocative efficiency. Productive efficiency is achieved when the quantity demanded is produced at the lowest possible cost. Allocative efficiency is achieved when the quantity demanded reflects the proper tradeoff of the cost of producing (and consuming) one product versus another.

In RTO energy markets, the commitment and dispatch solution is designed to achieve short-run productive efficiency – that is to produce the quantity demanded at each interval and across intervals at the lowest variable cost. Efficient prices must be consistent with that physical commitment and dispatch. If a unit that is economically dispatched does not receive energy market revenues that cover its variable costs, then the prices are not consistent with the dispatch. For prices to be completely consistent with the dispatch, each generator on the system has to be performing at an economic level, given the prices, and not be able to increase its profits by changing its output level up or down.

As I discussed above, and as illustrated by the simple example, the current energy pricing in PJM fails this simple test. There are both productive and allocative efficiency losses associated with this pricing failure – and that is why the Commission should be concerned.

Q. PLEASE EXPLAIN.

A. In economic terms, the current energy pricing regime in PJM is analogous to the pricing behavior of a partially discriminating monopsonist. I am using monopsony as an economic analogy here and I am not implying that PJM has any perverse intent. PJM, on behalf of the load in the footprint, buys the energy from the lowest cost producers, but it does not pay them all the same price for the energy they produce at the same time. Up to a point, all generators get the same price (the energy price, as calculated currently). But, some of the most expensive generators required to achieve a least cost dispatch, of which there might be one, ten or twenty or more on a given day, are each paid a different price that is in each case higher than the generally available energy price. In the example, the inflexible unit receives an effective price, including out of market uplift payments, of $20 per MWh, while the always-on and flexible units only receive the energy market clearing price of $10 to $15 per MWh.

Economics tells us what happens when this type of price discrimination occurs and why it is inefficient: what would and should be producer surplus under efficient pricing is instead converted to consumer surplus. All of the generators that just receive energy prices under-recover the efficient level of energy margin for every hour and day when the pricing does not support the dispatch. In the short run, a day or a month, this may not result in a significant productive efficiency penalty. But over the medium and longer

term, some of the otherwise economic generators that are harmed by this discrimination will leave the market.

As an illustration, we can return to the previous three-unit example. In this example, it is the always-on and flexible units that suffer from the inefficient price as those units effectively receive a lower price than the inflexible unit. Further, if there were other units running at the time, they would also receive the lower, inefficient price. To the extent that any of these generators withdraw from the market and would have remained in the market with efficient energy pricing, the retirement is "uneconomic" and increases the total cost of serving load, ultimately harming customers in the long run. In particular, the always-on unit, whose economics are analogous to a nuclear unit, would be particularly at risk of uneconomic retirement given that it has high fixed costs of operation that must largely be recovered through energy revenues. As I discussed in the first section of my testimony, many of the nuclear units in PJM are at risk of retirement as a result of the low level of energy margins, and the pricing inefficiency contributes to this retirement risk. Thus, the productive efficiency penalty could be quite substantial over time, and can be avoided through improved energy pricing.

Q. THUS FAR YOU HAVE JUST DISCUSSED THE POTENTIAL FOR PRODUCTIVE EFFICIENCY LOSSES. ARE THERE POTENTIAL ALLOCATIVE EFFICIENCY LOSSES, AS WELL?

A. Yes. In electricity energy markets, allocative efficiency is achieved when the "right" amount of electricity is consumed at the "right" time, consistent with efficient pricing.

As customer technology improves and becomes less expensive, sending efficient price signals on an hourly, fifteen minute, and five minute basis will become increasingly important to achieving allocative efficiency. While the amount of load that currently responds to hourly or real-time prices is not very large today, that proportion will likely grow substantially. So, by improving price formation to achieve prices that are consistent with the dispatch, the Commission should expect to realize both productive and allocative efficiency benefits over time.

Q. HASN'T THIS ENERGY PRICING INEFFICIENCY BEEN PRESENT FROM THE INCEPTION OF COMPETITIVE ENERGY MARKETS? WHY ARE CHANGES TO CORRECT ENERGY PRICE FORMATION ONLY BEING PROPOSED NOW?

A. It is correct that that this price formation inefficiency has been present since the inception of competitive markets. It is not true, however, that the problem is newly-identified, or that solutions to it have not been proposed previously. In fact, the problem of non-convexity in power markets has been well described since the inception of competitive power markets, and solutions to it have been proposed in that time frame as well, and in fact have served as the basis for a partial solution (Extended LMP) implemented in the Midcontinent ISO.[18]

[18] *See*, e.g. William W. Hogan and Brendan J. Ring, "On Minimum Uplift Pricing in Electricity Markets," March 19, 2003.

However, the problem of non-convexity has become more prevalent and apparent in recent years because of changes in market fundamentals, including very low natural gas prices, increased penetration by intermittent renewable resources, and low load growth. In prior years, higher gas prices and fewer low load / high renewables hours tended to mask the underlying problem. In recent years the flexible units setting prices during off-peak hours in PJM are more likely to be either renewables (which can vary their output via curtailment) which usually bid at either a zero or negative level, or natural gas combined-cycles with very low delivered natural gas prices. For example, between 2007 and 2012, the average PJM real-time energy price was below $20/MWH only about 3% of the hours, but the frequency of sub $20/MWH prices increased to 20% of the hours by 2016.[19] The frequency of very low prices is much higher at particular nodes – for example, at the Quad Cities nuclear plant, the real-time LMP was below $20/MWH for 47% of the hours in 2016.

Q. WHY DOES IT MATTER IF ENERGY PRICES DROP BELOW $20/MWH MORE FREQUENTLY?

A. That level of pricing would not be troubling if in fact, the marginal unit serving load during those hours was below $20/MWh. In PJM, however, there are numerous coal units, which have variable costs around or above $20/MWh, online in every hour of the

[19] Monitoring Analytics, LLC, *2016 State of the Market Report for PJM*, Table C-4.

year.[20] Thus, during hours where the price falls below $20/MWh the system will typically be relying on units whose variable costs exceed this level.

Q. WON'T ENERGY REVENUE SHORTFALLS FOR UNITS AFFECTED BY THIS INEFFICIENCY ULTIMATELY JUST BE RECOVERED THROUGH THE PJM CAPACITY MARKET?

A. No. Capacity markets, including PJM's Reliability Pricing Model ("RPM") are designed to procure sufficient capacity to ensure reliable supply during periods of peak demand at least cost. They are not, on their own, designed to produce an efficient least-cost mix of energy resources in all hours. That is primarily the role of the energy market, and, as I discussed, if the energy market is not producing efficient prices, it will not produce the least-cost mix of resources.

The demand curve in the RPM is calibrated based on the capacity revenues that a new peaking unit (a reference natural gas combustion turbine) needs to cover its costs, net of expected energy and ancillary services revenues. This energy offset calculation reflects only those high demand hours when such a unit would typically run, which are not typically the intervals when the pricing inefficiency results in prices that are too low. That is because the impact of the pricing inefficiency tends to be most prevalent and significant during low-load, off-peak hours when such a peaking unit would be offline. So the demand curve itself has not been "inflated" in any way due to the pricing

[20] I have analyzed publicly-available data on hourly unit-level output from the U.S. Environmental Protection Agency's Continuous Emission Monitoring System ("CEMS"). This data indicates that coal units were operating and producing output in every hour in PJM in 2015 and 2016.

inefficiency. In terms of the potential effect on capacity offers, many marginal supply bids in the RPM will be from peaking or intermediate resources such as combustion turbines and demand response whose energy margins, and hence capacity offers, are not significantly affected by the pricing inefficiency. To the extent that some marginal supply bids in the RPM are from resources impacted by the pricing inefficiency during certain hours (e.g., combined cycles), this could have some impact on the clearing price. The overall result of this is that RPM clearing prices based on the intersection of the peaker-calibrated demand curve and a supply curve reflecting the bids of many peaking resources will at most reflect only a portion of the energy revenue shortfalls borne by units affected by the pricing inefficiency, and will thus not offset these shortfalls. Over time, this will result in a bias in favor of peaking units at the expense of units which tend to run in all hours, which is not likely to produce the least cost mix of energy resources.

IV. THE IMM'S CRITICISMS OF PJM'S PROPOSAL ARE EITHER INCORRECT OR PREMATURE

Q. PLEASE SUMMARIZE THE IMM'S CRITICISMS OF PJM'S WHITE PAPER PROPOSAL.

A. The IMM has four major criticisms: 1) the PJM proposal would raise the cost to consumers with no counteracting decrease to production cost;[21] 2) the PJM proposed pricing solution is a fictitious solution that produces higher prices that are not consistent with the efficient dispatch of the market;[22] 3) the proposed pricing solution represents

[21] IMM Comments at 36.
[22] *Ibid.* at 37.

an "inappropriate" extension of the Commission's Fast Start Pricing NOPR;[23] and 4) the PJM proposal will have unintended consequences with respect to the incentives for flexible resources and for adverse economic behavior.[24]

Q. HOW DO YOU RESPOND?

A. As I explain below, none of the IMM's first three criticisms are valid. And the fourth is impossible to evaluate until more of the details of what PJM will propose are known.

There are two problems with the IMM's first criticism that the PJM proposal would raise costs to consumers without any offsetting production cost benefits. The first problem is that a comparison of cost increases to consumers against production cost savings is simply the wrong standard. The question presented by the price formation issue is whether energy prices that are inconsistent with economic commitment and dispatch are unjust and unreasonable and unduly discriminatory. If they are, then no "cost/benefit" test or comparison is required. This is merely a matter of ensuring that PJM's energy market is consistent with the basic economic theory on which it is based.

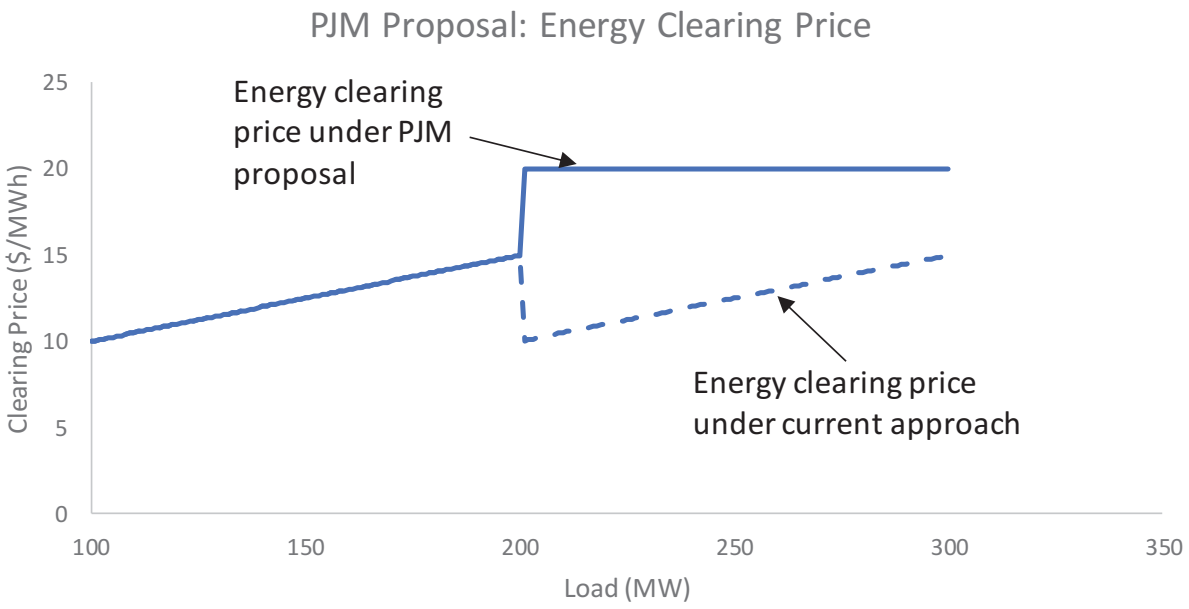
The second flaw in the IMM's argument is that the claim that there would be no production cost savings is simply untrue. As the preceding discussion of the productive efficiency benefits makes clear, lower production costs through avoided uneconomic retirement would be realized over time. In addition, efficient pricing could change the

[23] *Ibid.* at 36.
[24] *Ibid.* 40-41.

timing and mix of new supply, yielding additional productive efficiency benefits. Finally, it is possible that short-term production cost savings could also be realized, related to self-committed units. As the IMM observes, a number of long lead time or high startup cost units do not fit well into PJM's 24-hour day-ahead commitment, and self-commit instead. While that is rational way for these units to participate in the market, it is not without risk, and may not be optimal. Owners of these units must forecast prices over a multi-day period to decide when/whether to self-commit. To the extent energy prices are "too low" to support the dispatch for the reasons discussed above, the level of self-commitment may, in fact, be less than would otherwise be optimal. Under those circumstances, improved price formation could result in a more economic level of self-commitment, and lower production costs.

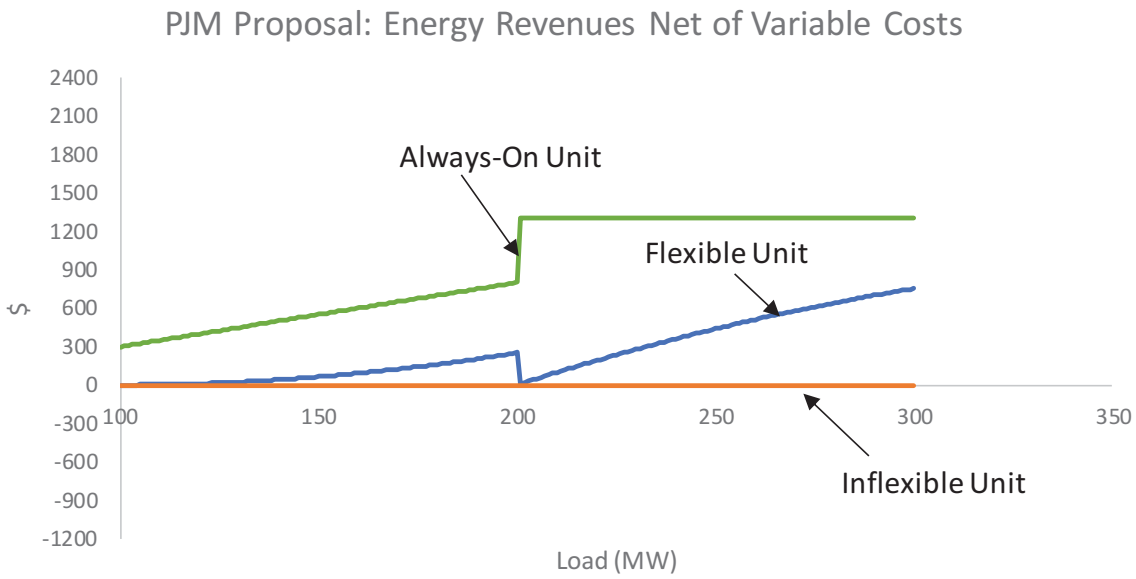
Q. WHAT ABOUT THE IMM'S SECOND CRITICISM THAT THE PJM PROPOSAL WOULD PRODUCE HIGHER PRICES THAT ARE NOT CONSISTENT WITH EFFICIENT DISPATCH?

A. I disagree. As I understand the approach that PJM is currently contemplating, the prices could sometimes be higher, but they would be consistent with the efficient dispatch, and would not be discriminatory. Let me illustrate this point by returning to the previous three-unit example discussed above. Under PJM's proposal, the dispatch would be the same as it is today. In the separate pricing run, the inflexible 100 MW unit with a variable cost of $20 per MWh would be represented as a flexible unit with a $20 per MWh variable cost. The prices that would result from this approach are shown below, together with the prices that result from the current approach.



From 100 MW through 200 MW of load, system marginal cost increases from $10 to $15 per MWh just as it would under the current pricing approach, following the marginal cost of the inflexible unit. At 201 MW and above, however, the inflexible unit is partially committed at an increasing rate, and thus sets the system marginal cost at $20/MWh.

The resulting energy clearing prices allow all three units to cover their variable costs at all load levels:



Because the price is $20/MWh over the range where the inflexible unit is committed, the inflexible unit breaks even, while the always-on and flexible units earn a positive energy margin. Thus, under PJM's proposal, the energy prices fully support the least-cost unit commitment.

However, from the load level of 201 MW to 299 MW (where the price of $20/MWh exceeds its variable cost), the flexible unit could increase its profits by dispatching at a higher level. Because of this, the flexible unit must be compensated for its lost opportunity cost to induce it to reduce its output to the level needed to avoid over generation. I discuss this out-of-market payment further below.

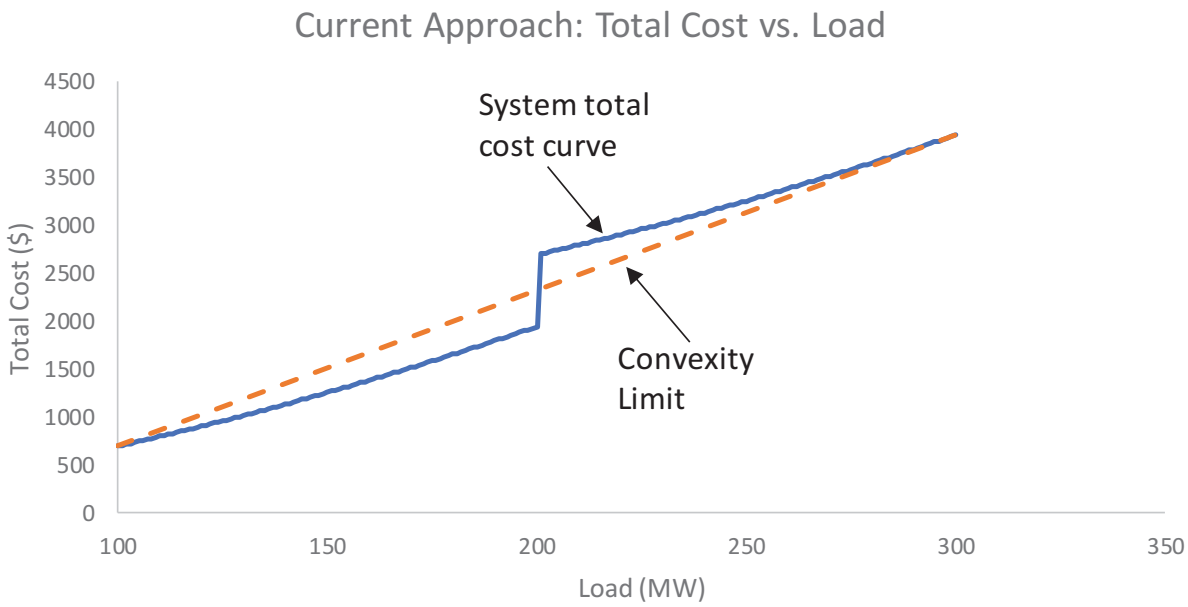
Q. TURNING TO THE IMM'S THIRD CRITICISM, IS PJM'S PROPOSAL AN INAPPROPRIATE EXTENSION OF THE FAST START NOPR PROPOSAL?

A. No. The Fast Start NOPR relates to the treatment of combustion turbines which can start quickly, but then typically must run at full output due to the physical characteristics of the unit. So, once the combustion turbine comes on, another unit must ramp down and becomes the "marginal" unit under PJM's current pricing approach. This is similar to the inflexible unit in my previous example, but a combustion turbine would typically have costs higher than $20/MWH. The solution discussed in the Fast Start NOPR is also similar to PJM's proposed solution which is to effectively let the inflexible resource set price.

The IMM believes that extending the Fast Start NOPR concepts to other inflexible units is inappropriate. I disagree. The pricing problem created by both inflexible fast start resources and inflexible baseload units is, in fact, the same problem. In both cases, we have a unit, or a portion of a unit which is either on or off, but which is part of a least cost commitment and dispatch. In both cases, the resulting prices under the current pricing rules are not sufficient to recover the variable costs of the inflexible unit, and hence are not consistent with the dispatch. In both cases, the pricing is inefficient. The only difference is that it is easier to "see" when the peaker was needed as part of the economic commitment and dispatch – it was needed when it was committed. But the key issue is not whether we know exactly when it was needed, but rather that we know it was part of an economic commitment and dispatch. In that respect, the minimum load portion of a coal unit can be thought of as a "slow start" peaker with a longer minimum run time. When it is economic to commit the slow start peaker, prices should

be consistent with that commitment just as the Fast Start NOPR would have prices consistent with the quick start peaker commitment.

The basic issue, which is common to both the slow start peaker and the fast start peaker is that the total cost of serving increasing levels of load, due to "on/off" segments, is not a smooth curve. To illustrate this point, let's return to my previous three-unit example. The total variable cost of production based on the efficient commitment and dispatch is shown in the chart below:



The minimum load level of 100 MW is served by the always-on unit at a cost of $700. From 100 MW to 200 MW of load, the flexible unit ramps up from 1 to 100 MW, with each incremental MW costing $0.05/MW more than the last MW to the point where total costs are $1950 at 200 MW, and marginal cost is $15/MWh. At 201 MW of load, however, a discontinuity appears because the inflexible unit is now needed to serve

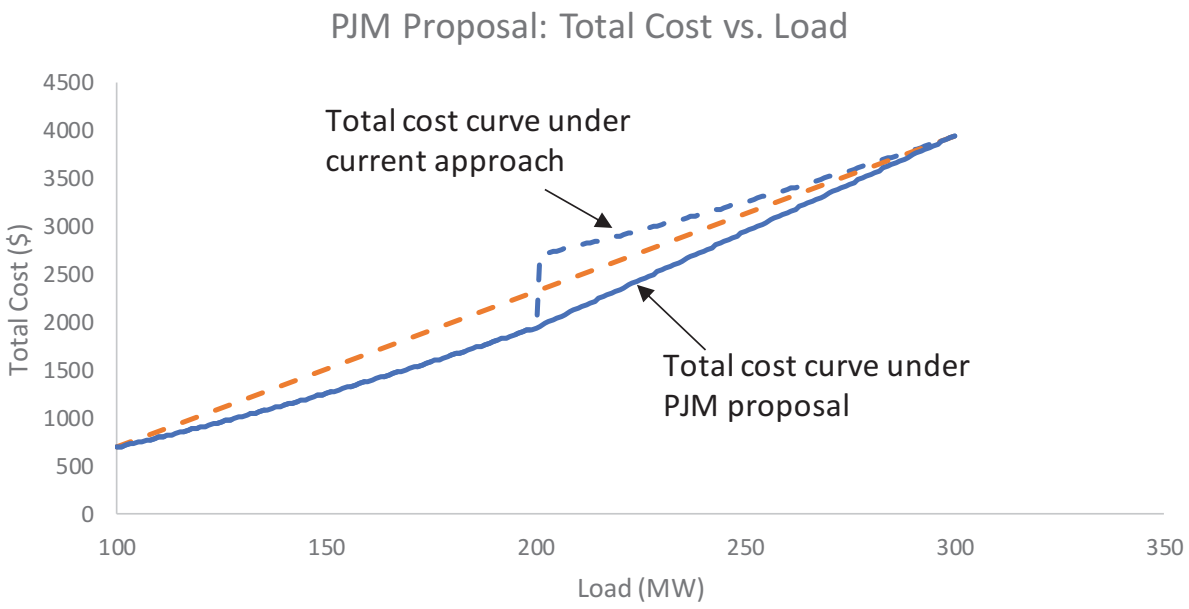
load. At this point the inflexible unit produces a fixed 100 MW of output and the flexible unit must ramp down to 1 MW of output to meet load. Total costs jump from $1950 at 200 MW to $2710 at 201 MW ($700 for the always-on unit, $2000 for the inflexible unit and $10 for the flexible unit). Moving from 201 to 202 MW the incremental cost falls back down to just over $10/MWh because the flexible unit returns to ramping up from 1 to 2 MW. This is indicative of what economists refer to as a non-convexity: the incremental cost of production is not continuously increasing with demand. Graphically, this can be seen by comparing the total cost curve to the straight line drawn between zero production and maximum production (shown in dashed red on the chart above). If any point on the total cost curve is above this line, the cost curve is non-convex. And if the total cost curve is non-convex, it means as system output increases, at some point marginal costs will decline, and prices based on marginal costs will not support the dispatch.

Much of micro-economic theory, and in particular the conclusion that short-term marginal cost is the efficient market price, is only valid under the assumption of a convex cost curve. But the electricity production cost curve is not convex because of operating constraints such as an on/off peaker or the minimum segment of an inflexible baseload unit. Despite significant economic literature on this point,[25] the IMM argues

[25] *See* e.g., Paul R. Gribik, William W. Hogan, and Susan L. Pope, "Market-Clearing Prices and Energy Uplift," Dec 31, 2007 ("Gribik et. al.").

that short-term marginal costs are always the right price and non-convexity should be selectively addressed rather than considered more broadly.

PJM's proposed energy price reform correctly considers all of the sources of non-convexity, not just on/off peakers, and would "relax" the on/off unit commitment decision for all inflexible units that are part of the economic commitment and dispatch, allowing the units to be partially committed in the pricing run and thus able to set price even when physically operating at their minimum output level. This change results in a convex total variable cost curve as shown below for the three-unit example:



The cost curve looks the same as the status quo through the 200 MW load point – the always-on unit serves the minimum 100 MW of load and then the lower cost flexible unit is committed first in either case – but at 201 MW load, rather than fully committing

the inflexible unit and ramping the flexible unit back to 1 MW, the pricing model partially commits the inflexible unit at an output level of 1 MW and leaves the inflexible unit at 100 MW. As a result, total costs increase from $1950 to $1970 as load moves from 200 to 201 MW, and continue to increase at $20/MW, the marginal cost of the inflexible unit, thereafter. Thus, the marginal cost curve, and energy clearing prices, are either increasing or constant with load level. This general approach of reforming the non-convex supply curve to be convex for purposes of setting prices has been well-established in the economic literature for over a decade and is the core economic concept underlying MISO's implementation of Extended Locational Pricing.[26] Given this history, the IMM's claim that "no economic theory supports allowing inflexible, baseload units to set price"[27] is surprising, and wrong. There is, in fact, a sound economic theory for allowing inflexible baseload units that are part of an economic commitment and dispatch to set price.

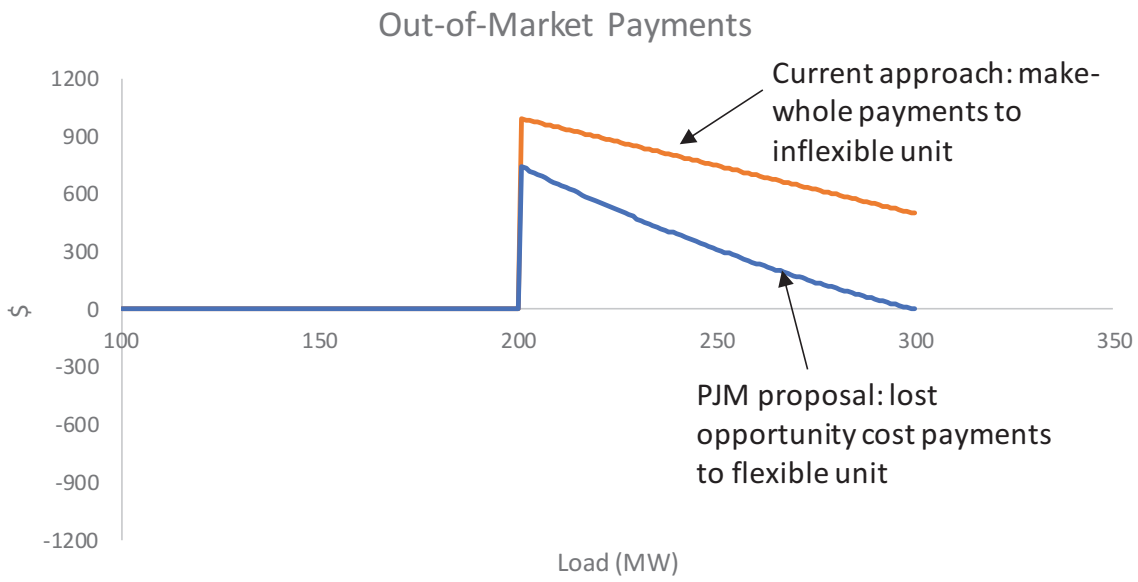
Q. WILL PJM'S PROPOSED APPROACH ELIMINATE OUT-OF-MARKET PAYMENTS?

A. PJM's approach should reduce, but will not eliminate out-of-market payments. Returning to the three-unit example, from the load level of 201 MW to 299 MW (where the price of $20/MWh exceeds its variable cost), the flexible unit could earn increased energy margin by increasing its output to its maximum level of 100 MW, as discussed

[26] *See* Gribik et. al. and Paul Gribik, Li Zhang, "Extended Locational Marginal Pricing (Convex Hull Pricing)," presentation at FERC Technical Conference on Unit Commitment Software, June 2-3, 2010, at 10-13. Available at https://www.ferc.gov/CalendarFiles/20100530130229-Gribik,%20Zhang,%20Midwest%20ISO%20-%20Extended%20LMP.pdf

[27] IMM Comments at 38.

above. While the flexible unit must be compensated for this lost opportunity cost to induce it to reduce its output to the level needed to avoid over-generation, these payments are lower than the payments which would need to be made to the inflexible unit under the status quo approach, as shown below.



Since out of market payments are required under the proposed PJM approach, it could be said that the prices are not completely consistent with the dispatch. But under PJM's proposed approach, units that are part of an economic commitment and dispatch will receive energy market revenues that are sufficient to cover their variable costs. Further, in contrast to the current pricing approach, the out of market payments are non-discriminatory in that all generating units receive revenues consistent with the same market clearing price. As a result, the efficiency losses associated with uneconomic retirement are avoided.

Q. DOES THE PJM PROPOSAL RESULT IN UNINTENDED CONSEQUENCES WITH RESPECT TO FLEXIBLE RESOURCES, AS SUGGESTED BY THE IMM?

A. The IMM suggests that the PJM Proposal "removes the economic incentive for the marginal resource to follow the dispatch signal."[28] This concern is speculative and premature because such incentives will be driven by design elements that PJM has not yet described in detailed terms. Further, in all likelihood, PJM's proposal will ultimately enhance, rather than reduce, incentives for generation to follow dispatch signals.

As noted previously, PJM's proposal will require out-of-market lost opportunity cost payments to induce certain generators to reduce output below their economically-optimal level to avoid physical over-generation. In its comments, PJM acknowledges the need for an appropriately-designed compensation mechanism to achieve this outcome, but does not at this point specify a solution. While care will be needed in designing such a compensation mechanism, the simple baseline lost opportunity cost payment ensures that resources will not have a disincentive to follow dispatch, and numerous options exist to provide an affirmative incentive for resources to follow the precise dispatch signal, such as penalties for failing to follow dispatch (or bonuses for doing so). Similar lost opportunity cost compensation mechanisms exist today in PJM's markets, such as in the synchronized reserve market and as uplift payments to resources scheduled in the day-ahead market but not committed in real-time, or to resources whose output level is restricted due to a reliability issue. While this will be an important element of PJM's

[28] *Ibid.* at 39.

ultimate proposal, it is a tractable issue and one that PJM has ample experience managing.

More fundamentally, the core problem with following dispatch raised by the IMM already exists in PJM's current market design, and PJM's proposal will make the problem better, rather than worse. As noted previously, in the current market, many inflexible units would generate less than the economic amount absent the out-of-market compensation paid to commit their units. This is the mirror image of the problem that the IMM describes, just applied to a different class of units. The PJM proposal largely eliminates the need for this type of uplift while reducing, but not eliminating, the overall amount of out-of-market compensation needed to induce units to follow dispatch. Thus, when viewed through this more holistic lens, the PJM Proposal improves, rather than reduces, the system-wide incentives for units to follow dispatch signals.

Q. DOES THE PJM PROPOSAL CREATE ADVERSE ECONOMIC INCENTIVES FOR SELF-COMMITMENT, AS SUGGESTED BY THE IMM?

A. The IMM suggests that the higher energy prices resulting from PJM's Proposal will lead to an inappropriate incentive for units to self-commit in the energy market, resulting in increased out-of-market payments and further price inefficiency. While PJM's Proposal lacks sufficient detail at this point to fully evaluate this concern, a properly-designed proposal will improve self-commitment incentives relative to the current pricing approach.

As noted previously, the core design principle underpinning PJM's proposal is the notion that all resources that are part of the least-cost solution should be eligible to set price, and the resulting market prices should support the least-cost solution. This principle should apply to both pool-scheduled resources[29] and self-scheduled resources that are part of the least-cost solution. It should not, however, apply to self-scheduled resources that are not part of the least-cost solution, and, by extension, if such resources were nonetheless self-committed, they should not be eligible to set price when running at minimum load. The key distinction here is the difference between economic and uneconomic resources, not the difference between pool-scheduled and self-scheduled resources. If a unit is part of the economic solution, it should be permitted to set price.

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes.

[29] PJM's Tariff defines pool-scheduled resources as "those resources for which Market Participants submitted offers to sell energy in the Day-ahead Energy Market and offers to reduce demand in the Day-ahead Energy Market, which [PJM] scheduled in the Day-ahead Energy Market as well as generators committed by [PJM] subsequent to the Day-ahead Energy Market." See PJM OATT, Section 1.10.2.

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Grid Reliability and Resilience Pricing	)	Docket No. RM18-1-000

DECLARATION OF MICHAEL M. SCHNITZER

I declare under penalty of perjury that the foregoing Prepared Testimony is true and correct.

Executed: November 7, 2017

Washington, DC

Michael M. Schnitzer

EXHIBIT A

white paper

Nuclear Costs in Context

Prepared by the

Nuclear Energy Institute

August 2017

NUCLEAR ENERGY INSTITUTE

The Nuclear Energy Institute is the nuclear energy industry's policy organization.

This white paper and additional information about nuclear energy are available at *nei.org*.

1201 F Street NW
Washington, DC 20004
NEI.org

Total Generating Costs

In 2016, the average total generating cost for nuclear energy was $33.93 per MWh (megawatt-hour). Total generating costs include *capital, fuel and operating costs* – all the costs necessary to produce electricity from a nuclear power plant. Cost information for the U.S. nuclear fleet is collected by the Electric Utility Cost Group (EUCG) with prior years converted to 2016 dollars for accurate historical comparisons.[1]

2016 Cost Summary ($/MWh)

Category	Number of Plants / Sites	Fuel	Capital	Operating	Total Operating (Fuel + Operating)	Total Generating (Fuel + Capital + Operating)
All U.S.	60*	6.76	6.74	20.43	27.19	33.93
Plant Size						
Single-Unit	25	6.77	8.67	25.95	32.72	41.39
Multi-Unit	35	6.75	6.15	18.73	25.48	31.63
Operator						
Single	12	7.18	8.19	21.20	28.38	36.57
Fleet	48	6.63	6.32	20.21	26.84	33.16

**Costs exclude shutdown plants.*
Source: Electric Utility Cost Group (EUCG)

Approximately 80 percent of the electricity generated from nuclear power in the U.S. comes from plants with multiple reactors. The economies of scale allow plant operators to spread costs more over multi-unit sites, resulting in a lower total generating cost. In 2016, the average total generating cost at multi-unit plants was $31.63 per MWh compared to $41.39 per MWh for single-unit plants.[2] This separation is driven by operations and capital costs as there is not a meaningful difference in fuel costs.

The 2016 total generating costs were 6 percent lower than in 2015 and more than 15 percent below the 2012 costs. Prior to the 2012 peak, nuclear generating costs had increased steadily over the previous decade, for various reasons. Between 2002 and 2016,

[1] EUCG data are collected to perform benchmarking comparisons by companies that operate nuclear plants. The total generating cost does not include considerations for risk management or returns on investment that would be key factors in business decisions affecting a particular station.
[2] The data provided are averages across the operating fleet. Individual plants may vary notably from the average due to factors such as geographic location, local labor costs and the timing of refueling outages.

fuel costs increased by 16 percent, capital expenditures by nearly 70 percent, and operating costs by more than 8 percent (in 2016 dollars per megawatt-hour). Total generating costs have increased by more than 18 percent in the last 14 years.

U.S. Nuclear Plant Costs (2016 $/MWh):

Year	Fuel	Capital	Operating	Total
2002	5.80	3.97	18.85	28.62
2005	5.09	5.88	19.21	30.18
2010	6.85	9.28	20.92	37.05
2011	7.19	10.20	22.18	39.58
2012	7.57	10.91	21.77	40.25
2013	7.84	8.32	21.22	37.37
2014	7.31	8.29	21.21	36.81
2015	6.95	8.07	21.11	36.13
2016	6.76	6.74	20.43	33.93
2002-2016 Change	**16.6%**	**69.8%**	**8.4%**	**18.6%**
2012-2016 Change	**-10.7%**	**-38.2%**	**-6.2%**	**-15.7%**

Capital Costs

Industry-wide, capital spending in 2016 decreased to $5.4 billion from $6.3 billion in 2015, compared to the peak of $8.8 billion in 2012 (all in 2016 dollars).

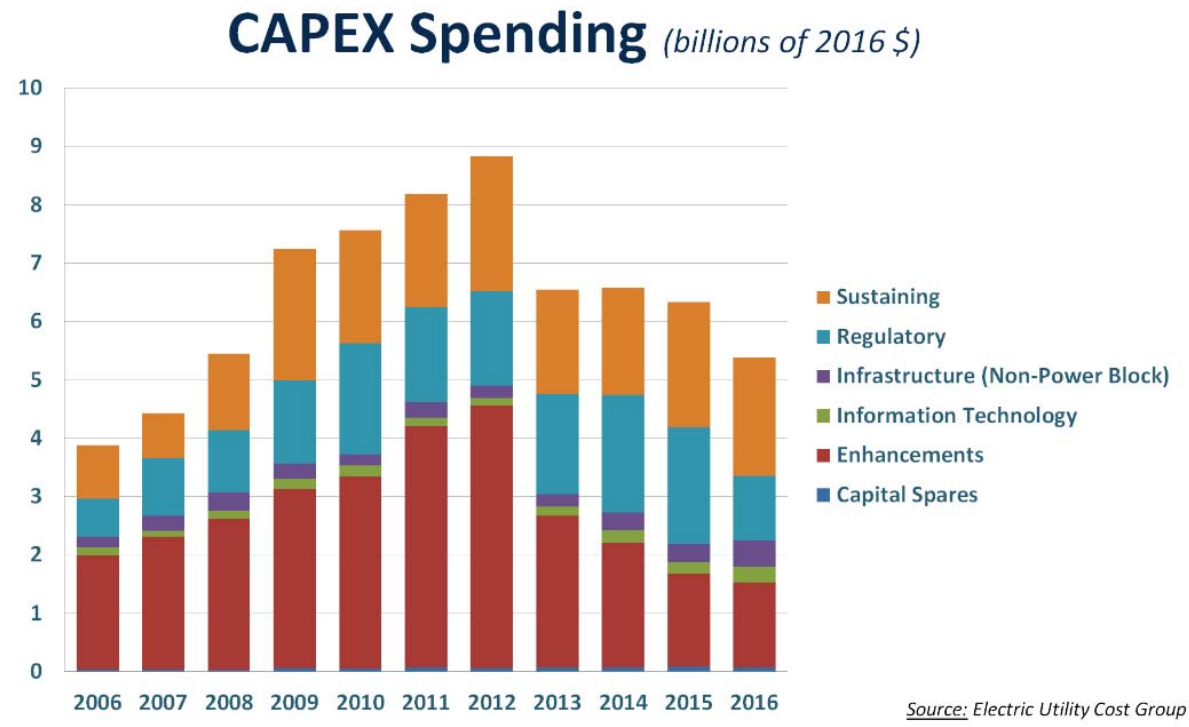
Capital investment saw a step-change increase around 2003 followed by steady increases until another step-change increase in 2009 and finally peaking in 2012. Capital costs have declined in each of the last four years. These inflections are the result of a few major items: a series of vessel head replacements, steam generator replacements and other upgrades as companies prepared their plants for operation after the initial 40-year license, and power uprates to increase output from existing plants. As a result of these investments, 84 of the 99 operating reactors have received twenty-year license renewals[3] and 92 of the operating reactors have been approved for uprates[4] that have added over 7,300 megawatts of capacity.

Capital spending on uprates and items necessary for operation beyond 40 years has moderated as most plants are completing these efforts. Investments in uprates peaked at $2.5 billion in 2012 but declined to $114 million in 2016. Some of this decline has been

[3] Nuclear Regulatory Commission: License Renewals Granted for Operating Nuclear Power Reactors. December 2016. https://www.nrc.gov/images/reading-rm/doc-collections/maps/power-reactors-license-renewals.png
[4] Nuclear Energy Institute: US Nuclear Power Uprates by Plant. June 2016. https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Power-Uprates-by-Plant

offset in other areas where spending has increased, however capital spending decreased notably in 2016 over 2015. Capital spending to meet regulatory requirements increased from approximately $1 billion in 2007 to approximately $1.9 billion in 2010 and peaked at $2 billion in 2014, before dropping to $1.1 billion in 2016 (all numbers in 2016 dollars). This increase began with significant investments post-9/11 to enhance security, followed by expenditures for post-Fukushima items, which peaked at $1.4 billion in 2015, before falling to $373 million in 2016. As the Fukushima-related safety upgrades are nearly completed, regulatory capex should also moderate, and revert toward 2007-2008 levels.

The chart below breaks down capital costs over the last decade.

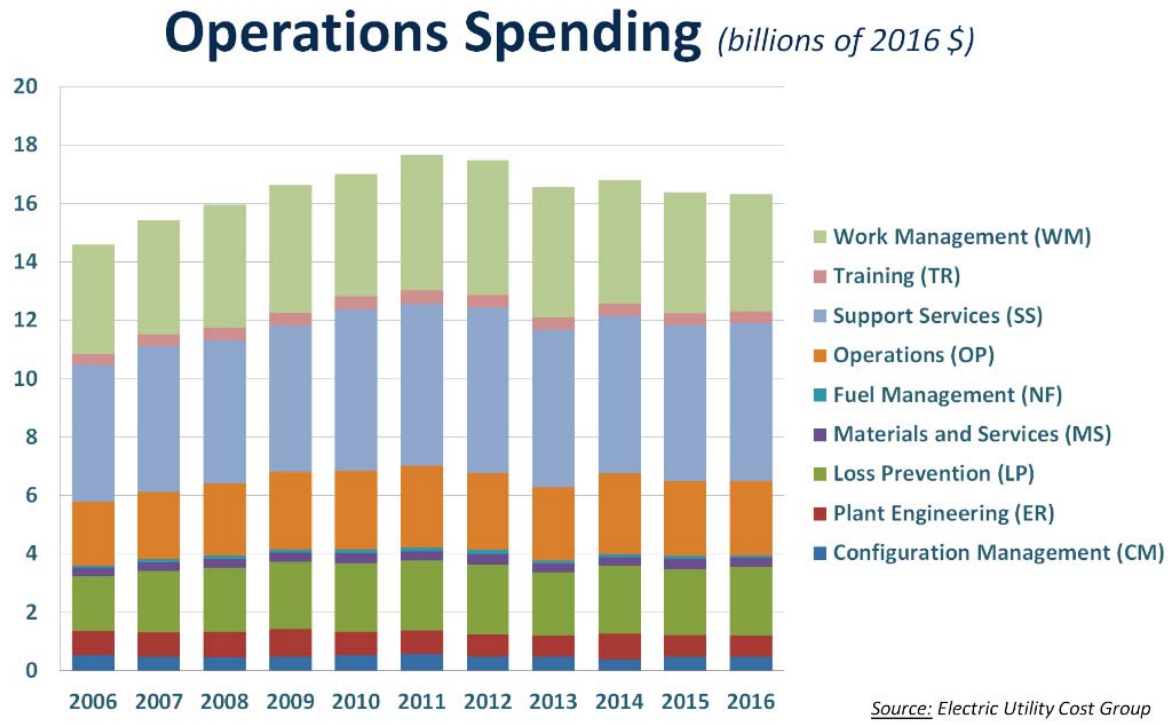


Operations

Operations costs increased over the last twelve years from $18.85 per megawatt-hour in 2002 to $20.43 per megawatt-hour in 2016. Operations costs have declined 8 percent from the peak in 2011.

This increase in operations costs was not driven by any single category. Operations costs in the 2002-2008 period are similar to where money was being spent in the 2009-2016 period. However, operations costs have remained flat compared to the past decade. Between 2002 and 2010, operations costs increased 11 percent while, over the past five years, operations costs have decreased by 6 percent.

The chart below breaks down operations spending over the last decade.



Fuel

Fuel costs represent 15-20 percent of the total generating cost. Fuel costs experienced a relatively rapid increase from 2009 to 2013. This was largely the result of an escalation in uranium prices, which peaked in 2008. Since uranium is purchased far in advance of refueling and resides in the reactor for four to six years, the effect of this commodity price spike persisted for a long time after the price increase actually occurred.

Economic Pressures Facing Nuclear Plants

Since 2013, six nuclear reactors (Crystal River 3 in Florida, San Onofre 2 and 3 in California, Kewaunee in Wisconsin, Vermont Yankee, and Fort Calhoun in Nebraska) have shut down permanently. Entergy announced in October 2015 that it would close its Pilgrim plant in Massachusetts by June 2019. In June 2016, Pacific Gas & Electric announced it would close both Diablo Canyon units by August 2025. In December 2016, Entergy announced it would close its Palisades plant in 2018. A month later, Entergy announced it would close Indian Point 2 and 3 by April 2021. In May 2017, Exelon announced that Three Mile Island would cease operations in 2019.

Crystal River and San Onofre shut down due to failed steam generator replacements – unique situations that are unlikely to be repeated. Since the Surry nuclear power plant in Virginia replaced its steam generators in the early 1980s, it has become a routine practice.

Diablo Canyon is retiring due to a combination policy and market pressures that created a situation where the plant could not optimally operate. Kewaunee, Vermont Yankee, Fort Calhoun, Palisades, Pilgrim and Indian Point, Three Mile Island – all in competitive markets

– succumbed to a combination of market-related factors (and, in some cases, a combination of several factors), including:

- Sustained low natural gas prices, which are suppressing prices in wholesale power markets, and will continue to do so.
- Relatively low growth (in some markets, no growth) in electricity demand due partly to subpar U.S. economic performance since the 2008 recession, partly to greater efficiency.
- Federal and state mandates for renewable generation, which suppress prices, particularly during off-peak hours (when wind generation is highest and the electricity is needed the least). For example, the federal production tax credit allows wind producers to bid negative prices, which places baseload plants at a disadvantage. Some nuclear plants in Illinois see negative prices as much as 10-11 percent of the off-peak hours and 5-6 percent of all hours.
- Transmission constraints, which require a power plant to pay a congestion charge or penalty to move its power on to the grid. Certain nuclear plants at particularly congested points on the grid pay a penalty of $6-9 per megawatt-hour to move their power out.
- Market designs that do not compensate the baseload nuclear plants for the value they provide to the grid, and market policies and practices – e.g., reliance on out-of-market revenues – that tend to suppress prices.

In the face of these pressures, additional plants will face the prospect of early closure unless policies are put in place to better reflect the value of the benefits provided by nuclear energy. New York and Illinois have enacted policies that will compensate nuclear plants for their environmental attributes, ensuring that a total of seven reactors in those two states will not be forced to shut down prematurely.

Economic Impact of Nuclear Plant Closures

The plants that have closed or announced closure were all highly reliable plants with high capacity factors and relatively low generating costs. Allowing these facilities to close will have long-term economic consequences: replacement generating capacity, when needed, will produce more costly electricity, fewer jobs that will pay less, and more pollution.

In 2016, on average, U.S. nuclear power plants produced electricity for less than $34 per megawatt-hour. The smaller single-unit plants like Kewaunee, Vermont Yankee and Fort Calhoun were a little more costly – about $41 per megawatt-hour. The larger, multi-unit sites were less costly – less than $32 per megawatt-hour range. The electricity these plants produce will likely be replaced with combined cycle gas-fired capacity at a levelized cost of $49 per megawatt-hour[5] according to the U.S. Energy Information Administration

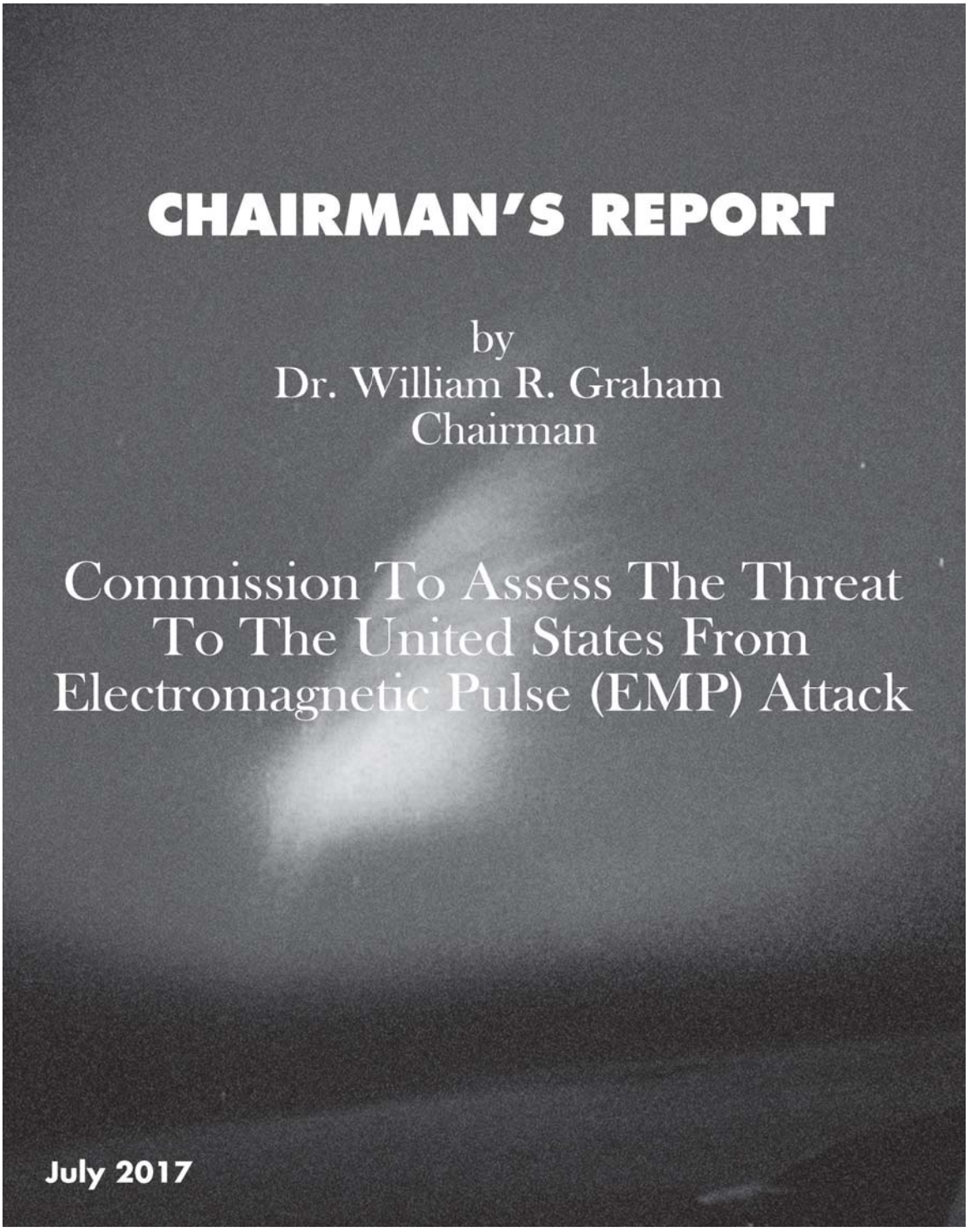
■

[5] U.S. Energy Information Administration: Annual Energy Outlook 2017 Levelized Costs – Appendix A. April 2017. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

From:	Joseph McClelland
To:	David Andrejcak; Harry Tom; (b) (6)
Cc:	(b) (6) ; (b) (6)
Subject:	FW: EMP COMMISSION CHAIRMAN"S REPORT
Date:	Wednesday, October 24, 2018 2:31:00 PM
Attachments:	FINAL EDITIONS.pdf

From: Peter Pry [mailto:peterpry@verizon.net]
Sent: Tuesday, October 23, 2018 4:49 PM
To: Joseph McClelland <Joseph.McClelland@ferc.gov>
Subject: EMP COMMISSION CHAIRMAN'S REPORT

Joe—Attached find an e-copy of the EMP Commission Chairman's Report recently cleared by DOD for unclassified publication. Beginning on p. 17, find the Russia, China, North Korea, and Iran perspective on nuclear EMP attack as potentially decisive, indeed the basis for a revolutionary new way of warfare that achieves victory by paralyzing civilian critical infrastructures and military forces. Available in hardcopy from Amazon.com Best Regards—Peter



The cover photo depicts Fishbowl Starfish Prime at 0 to 15 seconds from Maui Station in July 1962, courtesy of Los Alamos National Laboratory.

This report was produced to support the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. The Commission was established by Congress in the FY2001 National Defense Authorization Act, Title XIV, and was continued per the FY2016 National Defense Authorization Act, Section 1089.

The Commission completed its information-gathering in June 2017. The amended report was cleared for open publication by the Department of Defense Office of Prepublication and Security Review on July 27, 2018.

This report is unclassified and cleared for public release.

THIS REPORT WAS REVIEWED BY THE DEPARTMENT OF DEFENSE OFFICE OF PREPUBLICATION SECURITY REVIEW AND INCLUDES REDACTIONS.

REPORT TO THE COMMISSION TO ASSESS THE THREAT TO THE UNITED STATES FROM ELECTROMAGNETIC PULSE (EMP) ATTACK

Chairman's Report

by
Dr. William R. Graham
Chairman

Commission To Assess The Threat To The United States From Electromagnetic Pulse (EMP) Attack

July 2017

Acknowledgements

The author would like to thank Dr. Peter Pry for conducting the research and preparing most of the material in the section on EMP Attack and Combined-Arms Cyber Warfare.

Acronyms and Abbreviations

AQAP	Al Qaeda in The Arabian Peninsula
BMEWS	Ballistic Missile Early Warning System
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EEI	Edison Electric Institute
EHV	extra high voltage
EMP	electromagnetic pulse
EPRI	Electric Power Research Institute
FAA	Federal Aviation Administration
FDA	Food and Drug Administration
FERC	Federal Energy Regulatory Commission
FOBS	Fractional Orbital Bombardment System
GAO	Government Accountability Office
GMD	geomagnetic disturbances
HEMP	high-altitude electromagnetic pulse
JAEIC	Joint Atomic Energy Intelligence Committee
MNA	Mehr News Agency
NATO	North Atlantic Treaty Organization
NERC	North American Electric Reliability Corporation
PLA	People’s Liberation Army
PRC	People’s Republic of China
RFW	radio frequency weapon
RMA	revolution in military affairs
SCADA	supervisory control and data acquisition
SHSGA	Homeland Security and Government Affairs Committee

THIS REPORT WAS REVIEWED BY THE DEPARTMENT OF DEFENSE OFFICE OF PREPUBLICATION SECURITY REVIEW AND INCLUDES REDACTIONS.

Table of Contents

Abstract

The United States critical national infrastructure faces a present and continuing existential threat from combined-arms warfare, including cyber and manmade electromagnetic pulse (EMP) attack, and natural EMP from a solar superstorm. During the Cold War, the U.S. was primarily concerned about a high altitude nuclear-weapon generated EMP attack as a tactic by which the Soviet Union could suppress the U.S. national command authority and U.S. strategic forces' ability to respond to a nuclear attack, and thus destroy the U.S. deterrence value of assured nuclear retaliation. Within the last decade, newly-nuclear armed adversaries, including North Korea, have been developing the ability to deploy and threatening to carry out an EMP attack against the U.S. Such an attack would give North Korea and countries that have only a small number of nuclear weapons the ability to cause widespread, long-lasting damage to critical national infrastructures of the United States itself as a viable country and to the survival of a majority of its population.

While during the Cold War major efforts were undertaken by the Department of Defense (DoD) to assure that the U.S. national command authority and U.S. strategic forces could survive and operate after an EMP attack, no major efforts were then thought necessary by the national leadership to protect critical national infrastructures, provided that nuclear deterrence was successful. With the development of small nuclear arsenals and long-range missiles by small, hostile, potentially irrational countries, including North Korea, the threat of a nuclear EMP attack against the U.S. becomes one of the few ways that such a country could inflict devastating damage to the U.S. Therefore, it is critical that the U.S. national leadership address the EMP threat as an immediate, existential issue, and give a high priority to assuring the necessary leadership is engaged and the necessary steps are taken to protect the country from EMP. Otherwise, foreign adversaries may reasonably consider such an attack as one that can gravely damage the U.S. by striking at its technological Achilles' heel, without having to overcome the U.S. military.

Protecting and defending the national electric grid and other critical infrastructures from EMP can be accomplished at reasonable cost and minimal disruption to the present systems that comprise our critical infrastructure; all commensurate with Trump Administration plans to repair and improve U.S. infrastructures, increase their reliability, and strengthen our homeland defense and military capability.

I highly commend President Trump's new executive order "Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure" signed on May 11, 2017. I strongly recommend that implementation of cybersecurity for the electric grid and other critical infrastructures include EMP protection, since all-out cyber warfare as planned by Russia, China, North Korea, and Iran includes nuclear EMP attack, and integrating EMP and cyber-protection will be both the least expensive and most technically sound approach. Protecting against nuclear EMP will also protect

against natural EMP from solar super storms. The United States should not remain in our current state of existential vulnerability to well-known natural and manmade EMP threats. Such vulnerability invites attack.

The single most important action that must be taken immediately to advance national strength and survivability is:

> **Establish an Executive Agent, with the authority, accountability, and resources, to manage U.S. national infrastructure protection and defense against the existential EMP threat.** Current institutional authorities and responsibilities—government, industry, regulatory agencies—are fragmented, incomplete, inexperienced, under-resourced, and unable to protect and defend against foreign hostile EMP threats and solar super-storms.

Background and Recommendations

WE CAN PREVENT AN EMP CATASTROPHE

The United States—and modern electric power- and electronic-based civilization more generally—face present and continuing existential threats from naturally occurring and manmade EMP and Combined-Arms Cyber Warfare on our military and on our critical national infrastructures.

Protecting the national electric grid and other critical infrastructures from the most severe of these threats—nuclear EMP attack—could be done in a manner that protects against other electromagnetic threats, including geomagnetic storms. Extensively tested, performance-proven technologies for EMP hardening have been developed and implemented by the DoD to protect critical military systems for over 50 years, and can be ***affordably*** adapted to protect electric grids and other critical infrastructures, at a remarkably low cost relative to that of an EMP catastrophe. Such hardening should be applied in a prioritized manner, with the most important and difficult to replace assets being addressed first. For example, the nuclear reactors providing electric power in the U.S., along with their spent fuel storage facilities, should be given high priority.

President Trump's plan to repair and strengthen our national infrastructure, cyber security, homeland defense, and military capability presents an excellent opportunity to include measures for EMP protection that would mitigate the existential threats from solar super-storms *and* Combined-Arms Cyber Warfare.

A plausible long term nationwide blackout of the electric power grid and grid-dependent critical infrastructures—e.g., communications, public health, transportation, food-and-water supply—could disable most of our critical supply chains, leaving the U.S. in its condition prior to the advent of electric power in the 19th Century, when the national population was less than 60 million, but today without many of the past skills and assets necessary for our population to survive in those conditions. The result could be the death of a large fraction of the American people through the effects of starvation, disease, and societal collapse.

While national planning and preparation for such events could help mitigate the damage, outside the DoD few such actions are currently underway or even being contemplated. The United States, as the most technologically advanced nation in the world, is also the society most dependent upon electricity and electronics for survival and well-being. An extended national-scale blackout and loss of most electricity-dependent infrastructure could be induced by any of several threats:

Solar super-storms, like the 1859 Carrington Event, generate natural EMP that could blackout electric grids and other life-sustaining critical infrastructures over remarkably wide areas, putting

at risk the lives of many millions. Recurrence of another Carrington Event is inevitable. The National Aeronautics and Space Administration (NASA) reports the Earth was nearly impacted by a solar super-storm on July 23, 2012. NASA estimates the likelihood of such an event to be 12 percent per decade, virtually guaranteeing Earth will be impacted by a solar super-storm within the lifetimes of our grandchildren—and perhaps ourselves as well.

Nuclear EMP attack can be conducted with only a single nuclear weapon detonated at high altitude (a few dozen to several hundred kilometers) delivered either by satellite, a wide variety of long- and short-range missiles including some cruise and anti-ship missiles, a jet doing a zoom-climb, or even a high-altitude balloon. Some modes of such attacks could be executed relatively anonymously, thereby impairing attribution and therefore deterrence. Russia and China now have the capability to conduct a nuclear EMP attack against the U.S., and if not already at hand North Korea will soon have that capability. All have practiced or described contingency plans to do so. Terrorists or other less-sophisticated actors also might mount a nuclear EMP attack if they have access to a suitable nuclear explosive. Missile or other weapon delivery for EMP attack does not require a nuclear weapon re-entry system or accurate missile guidance.

Sabotage of the national grid by damaging extra-high-voltage (EHV) transformers using rifles, explosives, or non-nuclear EMP weapons could produce protracted and widespread blackouts by attacking less than a dozen major grid substations, according to the public statements of a past Chairman of the U.S. Federal Energy Regulatory Commission (FERC). At least one substantive rehearsal of such an attack may have already taken place: the sophisticated, damaging attack of the Metcalf electric substation in the San Francisco Bay Area.

Combined-Arms Cyber Warfare, as planned by Russia, China, North Korea, and Iran may use combinations of cyber-, sabotage-, and ultimately nuclear EMP-attack to impair the United States quickly and decisively by blacking-out large portions of its electric grid and other critical infrastructures. Foreign adversaries may also consider nuclear EMP attack as the ultimate cyber "denial of service" weapon, one which can gravely damage the U.S. by striking at its technological Achilles' heel, without having to engage the U.S. military. The synergism of such combined-arms is described in the military doctrines of all these potential adversaries as the greatest Revolution in Military Affairs (RMA) in history—one which anticipates rendering obsolete many, if not all, traditional instruments of military power.

While I highly commend President Trump's new Executive Order "Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure" signed on May 11, 2017, I strongly recommend that implementation of cybersecurity for the electric grid and other critical infrastructures include EMP protection, since all-out cyber warfare as planned by Russia, China, North Korea, and Iran includes nuclear EMP attack. However, current institutional arrangements for protecting and improving the reliability of the electric grids and other critical infrastructures through the U.S. FERC and the North American Electric Reliability

Corporation (NERC) are not designed to address major national security threats to the electric power grids and other national critical infrastructures. Using the U.S. FERC and NERC to achieve this level of national security is beyond the purpose for which those organizations were created and has proven to be fundamentally unworkable; new institutional arrangements are needed to advance preparedness to survive EMP and related threats to our critical national infrastructures.

I continue to recommend that U.S. critical national infrastructures be protected from EMP as outlined in our unclassified reports provided in 2004 and 2008, and elsewhere. Additional recommendations are provided in the present report. The single most important action that must be taken urgently to advance national strength and survivability is:

> **Establish an Executive Agent—a Cabinet Secretary designated by the President—with the authority, accountability, and resources, to manage U.S. national infrastructure protection and defense against EMP and the other existential threats described above.** Current institutional authorities and responsibilities—government, industry, regulatory agencies—are fragmented, incomplete, and unable to protect and defend against foreign hostile EMP threats and solar super-storms.

Additionally:

I encourage the President to work with Congressional leaders to stand-up a Joint Presidential-Congressional Commission, with its members charged with supporting the Nation's leadership and providing expertise, experience, and oversight to achieve, on an accelerated basis, the protection of critical national infrastructures. The U.S. FERC and NERC have for nearly a decade been unable or unwilling to implement the EMP Commission's recommendations. A Presidential-Congressional Commission on Critical Infrastructure Protection could engage the Free World's preeminent experts on EMP and Combined-Arms Cyber Warfare to serve the entire Government in a manner akin to the Atomic Energy Commission of the 1947-74 period, advising the Administration regarding actions to attain most quickly and most cost-effectively the protection essential to long-term national survival and wellbeing. The United States should not remain in our current state of fatal vulnerability to well-known natural and man-made threats.

I recommend, given the proximity and enormity of the threat from EMP and Combined-Arms Cyber Warfare, the President exercise leadership to implement immediate, mid-term, and long-term steps to deter and defeat this existential threat.

Immediately

I recommend that the President declare that EMP or cyber-attacks that blackout or threaten to blackout the national electric grid constitute the use of weapons of mass destruction that justify preemptive and retaliatory responses by the United States using all possible means, including nuclear weapons. Some potential adversaries have the capability to produce a protracted nationwide blackout induced by EMP and other elements of Combined-Arms Cyber Warfare. A Defense Science Board study *Resilient Military Systems and the Advanced Cyber Threat* (January 2013) equates an all-out cyber-attack on the United States with the consequences of a nuclear attack, and concludes that a nuclear response is justified to deter or retaliate for cyber warfare that threatens the life of the nation: "While the manifestations of a nuclear and cyber-attack are very different, in the end, the existential impact to the United States is the same."

I recommend that the President issue an Executive Order titled "Protecting the United States from Electromagnetic Pulse (EMP) Attack." Among many other provisions to protect the nation from EMP on an emergency basis, the Executive Order would instantly mobilize a much needed "whole of government solution" to the EMP and combined-arms cyber threat: "All U.S. Government Departments, Agencies, Offices, Councils, Boards, Commissions and other U.S. Government entities…shall take full and complete account of the EMP threat in forming policies and plans to protect United States critical infrastructures…" Protecting the electric grid and other critical infrastructures from the worst threat—nuclear EMP attack—can, if carried out in a system-wide, integrated approach, help mitigate all lesser threats, including natural EMP, man-made non-nuclear EMP, and cyber-attack, physical sabotage, and severe solar and terrestrial weather.

I recommend that the President direct the Secretary of Defense to include a Limited Nuclear Option for EMP attack among the U.S. nuclear strike plans, and immediately assure targeting and fusing capabilities for some of the nuclear forces to implement a nuclear EMP attack capability.

[redacted] If either or both of these satellites are nuclear-armed, they should be intercepted and destroyed over a broad ocean area where an EMP resulting from possible salvage-fusing will do the least damage.

I recommend that the President direct the Secretary of Defense to post Aegis ships in the Gulf of Mexico and near the east and west coasts, and the Secretary in turn should direct them to be prepared to intercept missiles from freighters, submarines, or other platforms that might launch a nuclear EMP attack on the United States. Ground-based U.S. National Missile Defenses (NMD) are primarily located in Alaska and California and oriented for a missile attack coming at

the U.S. from the north, and are not deployed to intercept a missile attack launched near the U.S. coasts or from the south.

I recommend that the President direct the Secretary of Homeland Security to harden the FirstNet emergency communications system against EMP.

I recommend that the President initiate Training, evaluating, and "Red Teaming" efforts to prepare the U.S., and in the event of an EMP attack to respond, and periodically report the results of these efforts and the state or national readiness to the Congress.

Mid-Term

I recommend that the President direct the Secretary of Defense to deploy Aegis-ashore missile interceptors along the Gulf of Mexico coast to fill the gap in U.S. missile defenses. [redacted]

I recommend that the President direct the Secretary of Defense to develop a space-surveillance program to determine if any satellites orbited over the United States are nuclear-armed, and develop space-interception capabilities to defend against nuclear-armed satellites that might make an EMP or other attack.

I recommend that the President direct the Nuclear Regulatory Commission to launch a crash program to harden the active nuclear power reactors and all spent fuel storage facilities against nuclear EMP attack. Even if the reactors and storage facilities survive an initial EMP attack, they currently are not able to restart generating power if there is no electric power available on its grid, and they typically only have enough emergency power to cool reactors and spent fuel facilities for several days, after which they would "go Fukushima," spreading radioactivity over adjacent areas.

Long-Term

The Commission recommends that the President through his Executive Agent protect elements of the national electric grid, the keystone critical infrastructure upon which all other critical infrastructures depend. Priority should be given to elements that are difficult and time-consuming to replace. Such elements can be protected from EMP at very low cost relative to the cost of an EMP catastrophe, and paid for without federal dollars by a slight increase in electric rates.

I recommend that a similar approach be taken to key elements of the national telecommunications infrastructure and other national critical infrastructures.

Progress Made by the Department of Defense

The statute re-establishing the EMP Commission directs it to evaluate and report on:

(1) The vulnerability of electric-dependent military systems in the United States to a manmade or natural EMP event, giving special attention to the progress made by the Department of Defense, other Government departments and agencies of the United States, and entities of the private sector in taking steps to protect such systems from such an event.

The DoD has been the primary federally funded organization to analyze, develop models, simulate, develop hardening technology, and using resources provided to it, to strengthen U.S. national security. The DoD has in the past sponsored much excellent work in these areas; however, even though it is the most knowledgeable federal agency in the field of EMP, it has:

1. Failed to transfer much of its technical capabilities and accomplishments to other agencies of the federal government;
2. Failed to use its knowledge to assist and critique activities of other federal agencies, including the intelligence community;
3. Failed to declassify EMP environment and effects data and predictions that, while known to U.S. adversaries, are not available to the U.S. public, U.S. infrastructure organizations, and U.S. professional societies that develop specifications and standards for protecting critical national infrastructure;
4. Failed to obtain the complete archive of Russian nuclear weapons effects data when offered for sale to the U.S. at modest cost in 1996;
5. Failed to inform the Congress and the public of the present and continuing existential EMP threat to the nation; and
6. Failed to develop and pursue plans to protect the U.S. from EMP threats.

Overall, for more than a decade, the DoD has been derelict in its duties to lead the country in providing for national defense and security from EMP attack. This dereliction of duty should not be allowed by the leadership of the Administration and the Congress to continue.

I recommend the development and deployment of enhanced-EMP nuclear weapons and other means to deter adversary attack on the United States. Enhanced-EMP nuclear weapons, called by the Russians Super-EMP weapons, can be developed without nuclear testing.

I recommend strengthening U.S. ballistic missile defense, deploying it to protect the U.S. from attack from near-by oceans as well as from longer distances, including by development and deployment of space-based defenses.

The EMP Commission History

The Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack was first established by Congress in the FY2001 Floyd D. Spence National Defense Authorization Act, Title XIV, following 5 years of classified and unclassified hearings by Congress to ascertain if Russia, China, rogue states or terrorists had plans and capabilities to make an EMP attack. The final impetus to establish the EMP Commission was provided in April 1999, during the bombing of former Yugoslavia by the North Atlantic Treaty Organization (NATO), when a congressional delegation meeting in Vienna to discuss the Balkans crisis with senior members of the Russian Duma were threatened with a "hypothetical" nuclear EMP attack against the United States.

Under the Congressional EMP Commission's original statutory charter, Public Law 106-398, Title XIV, Section 1402 Duties of Commission:

> ***(a) Review of EMP Threat. The Commission shall assess:***
>
> *(1) the nature and magnitude of potential high-altitude EMP threats to the United States from all potentially hostile states or non-state actors that have or could acquire nuclear weapons and ballistic missiles enabling them to perform a high-altitude EMP attack against the United States within the next 15 years;*
>
> *(2) the vulnerability of United States military and especially civilian systems to an EMP attack, giving special attention to vulnerability of the civilian infrastructure as a matter of emergency preparedness;*
>
> *(3) the capability of the United States to repair and recover from damage inflicted on United States military and civilian systems by an EMP attack; and*
>
> *(4) the feasibility and cost of hardening select military and civilian systems against EMP attack.*
>
> *(b) Recommendation. The Commission shall recommend any steps it believes should be taken by the United States to better protect its military and civilian systems from EMP attack.*

Between 2001 and 2008, the Congressional EMP Commission produced several reports addressing the EMP threat to U.S. military systems and making recommendations. The EMP Commission produced two unclassified reports addressing EMP threats to critical national infrastructures:

Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume I: Executive Report (2004)

Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures (2008)

The above unclassified reports on civilian critical infrastructures addressed EMP threats to:

- infrastructure commonalities, including Supervisory Control And Data Acquisition (SCADA) systems,
- electric power, identified as the "keystone critical infrastructure" upon which all others depend,
- telecommunications,
- banking and finance,
- petroleum and natural gas,
- transportation,
- food,
- water,
- emergency services,
- space systems, and
- government.

The EMP Commission *Executive Report* summarized the problem as below:

Several potential adversaries have or can acquire the capability to attack the United States with a high-altitude nuclear weapon-generated EMP. A determined adversary can achieve an EMP attack capability without having a high level of sophistication.

EMP is one of a small number of threats that can hold our society at risk of catastrophic consequences. EMP will cover the wide geographic region within line of sight to the nuclear weapon. It has the capability to produce significant damage to critical infrastructures and thus to the very fabric of U.S. society, as well as to the ability of the United States and Western nations to project influence and military power.

The common element that can produce such an impact from EMP is primarily electronics, so pervasive in all aspects of our society and military, coupled through critical infrastructures. Our vulnerability is increasing daily as our use of and dependence on electronics continues to grow. The impact of EMP is asymmetric in relation to potential protagonists who are not as dependent on modern electronics.

The current vulnerability of our critical infrastructures can both invite and reward attack if not corrected. Correction is feasible and well within the Nation's means and resources to accomplish.

The Congressional EMP Commission 2004 *Executive Summary* stated in "Overview: EMP Is Capable of Causing Catastrophe for The Nation" several additional salient points about the nuclear EMP threat:

- *The recovery of any one of the key national infrastructures is dependent on the recovery of others. The longer the outage, the more problematic and uncertain the recovery will be. It is possible for the functional outages to become mutually reinforcing until at some point the degradation of infrastructure could have irreversible effects on the country's ability to support its population.*
- *EMP effects from nuclear bursts are not new threats to our nation…What is different now is that some potential sources of EMP threats are difficult to deter—they can be terrorist groups that have no state identity, have only one or a few weapons, and are motivated to attack the U.S. without regard for their own safety.*
- *Rogue states, such as North Korea and Iran, may also be developing the capability to pose an EMP threat to the United States, and may also be unpredictable and difficult to deter.*
- *Certain types of relatively low-yield nuclear weapons can be employed to generate potentially catastrophic EMP effects over wide geographic areas, and designs for variants of such weapons may have been illicitly trafficked for a quarter-century.*
- *China and Russia have considered limited nuclear attack options that, unlike their Cold War plans, employ EMP as the primary or sole means of attack.*
- *Another key difference from the past is that the U.S. has developed more than most other nations as a modern society heavily dependent on electronics, telecommunications, energy, information networks, and a rich set of financial and transportation systems that leverage modern technology.*
- *Therefore, terrorists or state actors that possess relatively unsophisticated missiles armed with nuclear weapons may well calculate that, instead of destroying a city or military base, they may obtain the greatest political-military utility from one or a few such weapons by using them—or threatening their use—in an EMP attack.*

The Congressional EMP Commission 2008 report *Critical National Infrastructures* made over 100 recommendations to protect the civilian critical infrastructures from nuclear EMP attack and other hazards. The EMP Commission endorsed an "all hazards" strategy as the most cost-effective approach to protecting the critical infrastructures, wherever possible using measures that would safeguard against multiple threats—including nuclear EMP, natural EMP or geomagnetic disturbance (GMD) from solar storms, intentional and accidental electromagnetic interference, cyber-attack, sabotage, and severe weather.

While the Congressional EMP Commission accurately described nuclear EMP attack as an existential threat to the United States, the thrust of the Commission's 2004 and 2008 reports was to recommend how to protect the nation cost-effectively, noting that protection is possible "and well within the Nation's means and resources to accomplish."

Congressional efforts to re-authorize the EMP Commission became more urgent because of misleading and inaccurate reports that are impeding implementation of the EMP Commission recommendations and are making the nation more vulnerable. For example:

- The NERC and the Edison Electric Institute (EEI) in 2012 and subsequently published a series of reports underestimating EMP threats from nuclear attack and from solar storms. These resulted in approval by the U.S. FERC of an inadequate natural EMP and GMD Standard for protecting electric grids, and impeded initiatives by several States to protect their grids from EMP.
- The Joint Atomic Energy Intelligence Committee in 2014 published a report on the EMP threat that is factually inaccurate and deeply flawed analytically, and has impeded implementation of EMP Commission recommendations.
- In 2016, the Electric Power Research Institute (EPRI), which is funded by the electric power industry, published an erroneous report that significantly underestimates the nuclear E3 EMP threat to electric grids. EPRI and others have used the report to lobby against Federal and State initiatives to protect the electric grid against nuclear EMP attack.
- In 2016, a report by the U.S. Government Accountability Office (GAO) concluded, "[U.S. Department of Homeland Security] DHS and [U.S. Department of Energy] DOE, in conjunction with industry, have not established a coordinated approach to identifying and implementing key risk management activities to address EMP risks." Congressional hearings subsequently confirmed that little or nothing has been done to implement EMP Commission recommendations to protect the electric grid.

Moreover, since the EMP Commission terminated in 2008, growing geopolitical instability, increased risk of war in the Middle East, Asia, and Europe, increasing threats from global terrorism, and increased awareness of natural EMP threats from the Sun—all have heightened congressional concerns about dangers to the electric grid from EMP and other threats. For example:

- North Korea in 2012 and 2016, amidst threats to annihilate the United States and a rapidly advancing nuclear missile program, orbited two satellites in polar orbits that cross over the U.S. on trajectories consistent with practice or preparation for a surprise nuclear EMP attack.
- On June 9, 2014, Al Qaeda in the Arabian Peninsula sabotaged the Yemen electric grid, inducing a temporary nationwide blackout of 19 cities and 24 million people. It is the first time in history that a terror attack has blacked-out an entire nation.

- On March 31, 2015, Turkey experienced a temporary nationwide blackout, allegedly from a cyber-attack by Iran, later denied by the Turkish government. On December 23, 2015, Western Ukraine was blacked-out temporarily by a cyber-attack from Russia. One of these is the first time in history that a large-scale blackout has been induced by cyber-attack.
- On July 23, 2012, the Earth was narrowly missed by a large coronal mass ejection from the Sun that NASA assessed could have caused a protracted worldwide blackout with potentially catastrophic consequences. NASA estimates the likelihood of a potentially catastrophic worldwide natural EMP event from a solar super-storm is 12 percent per decade.

In response to these events and others, Congress re-established the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack in the FY2016 National Defense Authorization Act, Section 1089. The renewed EMP Commission has a broader agenda, to assess threats to the U.S. military and civilian critical infrastructures from nuclear EMP, non-nuclear EMP weapons, cyber-attack, sabotage, and solar storms:

(d) Expanded PURPOSE. —Section 1401(b) of the Commission charter (114 Stat. 1654A–345) is amended by inserting before the period at the end the following: ", from non-nuclear EMP weapons, from natural EMP generated by geomagnetic storms, and from proposed uses in the military doctrines of potential adversaries of using EMP weapons in combination with other attack vectors."

(e) DUTIES OF COMMISSION. —*Section 1402 of the Commission charter (114 Stat. 1654A–346) is amended to read as follows:*

SEC. 1402. **DUTIES OF COMMISSION**.

The Commission shall assess the following:

(1) The vulnerability of electric-dependent military systems in the United States to a manmade or natural EMP event, giving special attention to the progress made by the Department of Defense, other Government departments and agencies of the United States, and entities of the private sector in taking steps to protect such systems from such an event.

(2) The evolving current and future threat from state and non-state actors of a manmade EMP attack employing nuclear or non-nuclear weapons.

(3) New technologies, operational procedures, and contingency planning that can protect electronics and military systems from the effects of a manmade or natural EMP event.

(4) Among the States, if State grids are protected against manmade or natural EMP, which States should receive highest priority for protecting critical defense assets.

(5) The degree to which vulnerabilities of critical infrastructure systems create cascading vulnerabilities for military systems.

EMP Attack and Combined-Arms Cyber Warfare

Nuclear EMP attack is part of the military doctrines, plans and exercises of Russia, China, North Korea, and Iran for a revolutionary new way of warfare against military forces and civilian critical infrastructures by cyber, sabotage, and EMP. This new way of warfare is called many things by many nations. In Russia, China, and Iran it is called Sixth Generation Warfare, Non-Contact Warfare, Electronic Warfare, Total Information Warfare, and Cyber Warfare. Some U.S. analysts—the very small number paying attention—call it Cybergeddon, Blackout War, or Combined-Arms Cyber Warfare.[1]

Significantly, EMP attack entails detonating a nuclear weapon at such high altitude that no blast or other prompt effects injurious to humans are delivered other than possible eye burn to those looking near the burst point. Since EMP immediately damages only electrical and electronics components and systems, potential adversaries do not appear to regard nuclear EMP attack as an act of nuclear warfare.

Potential adversaries understand that millions could die from the long-term collateral effects of EMP and cyber-attacks that cause protracted black-out of national electric grids and other life-sustaining critical infrastructures. At least some regard this relatively easy, potentially anonymous, method of inflicting mass destruction as an attractive feature of what they describe as a Revolution in Military Affairs.

Ignorance of the military doctrines of potential adversaries and a failure of U.S. strategic imagination, as noted in military writings of potentially hostile powers, is setting America up for an EMP Pearl Harbor.[2] Russia, China, North Korea and Iran appear to regard nuclear EMP attack as the ultimate weapon in an all-out cyber operation aimed at defeating U.S. and allied military forces on the battlefield and in a theater of operations. They also see EMP and Combined-Arms Cyber Warfare as a means of defeating entire nations by blacking-out their electric grids and other critical infrastructures for longer periods of time than technologically developed societies, including the U.S., can tolerate without major disruption and loss of life.[3]

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1 While many analysts are paying attention to cyber warfare, narrowly defined as the use of computer viruses and hacking and other such techniques, relatively few conceive of "cyber warfare" as potential adversaries do— as Combined-Arms Cyber Warfare entailing coordinated use of computer viruses etc., sabotage and kinetic attack, non-nuclear and nuclear EMP weapons. Dr. Peter Vincent Pry, *Blackout Wars* (Task Force on National and Homeland Security, 2015), Chapter II "The Blackout War".

2 For Example: Zhang Shouqi and Sun Xuegui, "Be Vigilant Against 'Pearl Harbor' Incident in The Information Age" Jiefangjun Bao (Official newspaper of the PRC People's Liberation Army, May 14, 1996).

3 Ambassador R. James Woolsey, "Heading Toward An EMP Catastrophe" Statement for the Record before the Senate Homeland Security and Governmental Affairs Committee, July 22, 2015.

Russia

For example, Russian General Vladimir Slipchenko in his military textbook *Non-Contact Wars* describes the combined use of cyber viruses and hacking, physical attacks, non-nuclear EMP weapons, and ultimately nuclear EMP attack against electric grids and critical infrastructures as a new way of warfare that is the greatest Revolution in Military Affairs in history. Like Nazi Germany's Blitzkrieg ("Lightning War") Strategy that coordinated airpower, armor, and mobile infantry to achieve strategic and technological surprise that nearly defeated the Allies in World War II, the New Blitzkrieg is, literally and figuratively, an electronic "Lightning War" so potentially decisive in its effects that an entire civilization could be overthrown in hours.[4]

According to General Slipchenko, EMP and the new RMA renders obsolete modern armies, navies and air forces. For the first time in history, small nations or even non-state actors can humble the most advanced nations on Earth.

An article in ***Military Thought***, the flagship journal of the Russian General Staff, "Weak Points of the U.S. Concept of Network-Centric Warfare" points to nuclear EMP attack as a means of defeating the United States: "American forces may be vulnerable to electronic warfare attacks, in particular, an electromagnetic pulse that is a brief powerful electromagnetic field capable of overloading or destroying numerous electronic systems and high-tech microcircuits that are very sensitive to the electromagnetic field, even if transmitted from a distance. A single low-yield nuclear weapon exploded for this purpose high above the area of combat operations can generate an electromagnetic pulse covering a large area and destroying electronic equipment without loss of life that is caused by the blast or radiation."[5]

Moreover: "Today, too, a considerable body of administrative information in the U.S. armed forces goes through the civilian Internet. Many commercial communication satellites, particularly satellites in low orbits, can have their functions impaired or they can be disabled by electromagnetic shocks from high altitudes."[6]

A 2015 article from Russia's A.A. Maksimov Scientific Research Institute for Space Systems, alludes to low-yield nuclear enhanced-EMP as the most effective cyber weapon: "Even more effective are remote-controlled cyber weapons in the nuclear variant, but in this case a warhead

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4 Major General Vladimir Ivanovich Slipchencko, *Non-Contact Wars* (Moscow: 2000). See also Slipchenko, *Future War* (Moscow Public Science Foundation, 1999).

5 Colonel A.V. Kopylov, "Weak Points of the U.S. Concept of Network-Centric Warfare" Military Thought (Moscow: Volume 3, 2011).

6 Ibid.

is required with a capacity many times smaller by comparison with the charges of the typical strategic missiles."[7]

Russia's then First Deputy Minister of Defense, Andrey Kokoshin, in a 1997 interview, claimed Russia was developing nuclear weapons "that have no counterparts in the world," including something that sounds suspiciously like a Super-EMP weapon: "ultra-small nuclear warheads weighing less than 90 kilograms, which are already being manufactured…and radiofrequency weapons."[8] In Russian military writings, the phrase "radiofrequency weapons" is used to describe nuclear or non-nuclear weapons designed to destroy enemy electronics by means of EMP.

China

China's military doctrine sounds an identical theme. According to People's Liberation Army Textbook *World War, the Third World War—Total Information Warfare*, written by Shen Weiguang (allegedly, according to the People's Republic of China (PRC), the inventor of Information Warfare), "Therefore, China should focus on measures to counter computer viruses, nuclear electromagnetic pulse...and quickly achieve breakthroughs in those technologies...":

> *With their massive destructiveness, long-range nuclear weapons have combined with highly sophisticated information technology and information warfare under nuclear deterrence....Information war and traditional war have one thing in common, namely that the country which possesses the critical weapons such as atomic bombs will have "first strike" and "second strike retaliation" capabilities....As soon as its computer networks come under attack and are destroyed, the country will slip into a state of paralysis and the lives of its people will ground to a halt. Therefore, China should focus on measures to counter computer viruses, nuclear electromagnetic pulse...and quickly achieve breakthroughs in those technologies in order to equip China without delay with equivalent deterrence that will enable it to stand up to the military powers in the information age and neutralize and check the deterrence of Western powers, including the United States.*

An article "Overview of Electromagnetic Pulse Weapons and Protection Techniques Against Them" from the People's Republic of China Air Force Engineering University describes nuclear EMP weapons as the most powerful and effective variant of electronic warfare weapons for waging Information Warfare. Nuclear and non-nuclear EMP weapons in the context of

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7 Dr. Grigoriy Vokin, Department Chief, "Remote Custodian. Warheads with Artificial Intelligence for Reconnaissance, Guaranteed Destruction of Targets, and Human Rescue" A.A. Maksimov Scientific Research Institute for Space Systems (2015).

8 Denis Baranets, Komsomolskaya Pravda (7 August 1997), p. 1.

Information Warfare are the crucial instruments for implementing this Revolution in Military Affairs:

> *In future high-tech warfare under informatized conditions, information warfare will span multiple dimensions, including ground, sea, air, and the EM spectrum. Information superiority has already become central and crucial to achieving victory in warfare…If the communications equipment used for the transmission of battlefield information were attacked and damaged by an opponent's EMP weapons, then the one attacked would face the danger of disruption in battlefield information transmission. EMP severely restricts the tactical performance and battlefield survivability of informatized equipment.*[9]

Moreover, the article clearly makes a distinction between nuclear weapons and nuclear EMP weapons, describing the latter as "a new type of weapon" like non-nuclear EMP weapons for waging Information Warfare:

> *As opposed to conventional and nuclear weapons, EMP weapons are a new type of weapon capable of causing mass destruction by instantly releasing high-intensity EMP…They can interfere, damage, and overheat electronics, resulting in logic circuit dysfunctions, control malfunctions, or total failure. The unique destructive effect that EMP have on electronic equipment was unintentionally discovered by the United States in the 1960s during a nuclear test. In July 1962, the United States conducted a high-altitude nuclear explosion in the Pacific Ocean. This…unexpectedly overloaded the Honolulu power grid in Hawaii, 1,400 km away, even overheating lightning protection devices on powerlines. On a battlefield, this new-type weapon will cause devastating damage to electronic systems, including computers, communications and control systems, and radars, resulting in immeasurable losses.*[10]

Furthermore, according to the article: "There are 3 types of military EMP based on pulse sources: the first is the high-altitude electromagnetic pulse (HEMP) produced by the detonation of a low yield nuclear bomb in the atmosphere at high-altitude; the second is…produced by high explosives and related devices; the third is the HPM…produced by HPM devices such as magnetrons and vircators." Nuclear EMP weapons are, or include, Enhanced-EMP or so-called Super-EMP weapons designed to produce gamma rays and high-frequency E1 EMP: "HEMP weapons are a type of weak nuclear explosive EMP bomb that produces EMP through the detonation of low-yield nuclear bombs at high-altitudes (70 to 100 km above ground)." The E1

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9 Zhao Meng, Da Xinyu, and Zhang Yapu, "Overview of Electromagnetic Pulse Weapons and Protection Techniques Against Them" Winged Missiles (PRC Air Force Engineering University: May 1, 2014).

10 Ibid.

EMP field "produced by nuclear EMP is about 10 to 100 kV/m and can penetrate and melt any electronic components."[11]

A January 2016 article "General Trend of the Worldwide Revolution in Military Affairs and the Form of Future War" by China's National Security Policy Committee sees "electromagnetic pulse bombs" among the new "disruptive technologies" that "can change the 'rules of the game'" by disrupting U.S. military "precision warfare capabilities centered on information technology" thereby sounding "the horn of a new round of revolution in military affairs."[12]

Iran

A recently translated military textbook ironically titled *Passive Defense* by the Army of the Islamic Republic of Iran (Martyr Lt. General Sayed Shirazi Center for Education and Research, 2010) endorses the theories of Russian General Slipchenko (who is acknowledged on page one of the first chapter).[13] The military manual notes the potentially decisive effects of nuclear EMP attack to defeat an adversary in more than 20 passages. Ambassador R. James Woolsey, former Director of Central Intelligence, writes:

> *"Death to America" is more than merely an Iranian chant—Tehran's military is planning to be able to make a nuclear EMP attack....Rep. Trent Franks quoted from an Iranian military textbook recently translated by the Defense Intelligence Agency's National Intelligence University...The official Iranian military textbook advocates a revolutionary new way of warfare that combines coordinated attacks by nuclear and non-nuclear EMP weapons, physical and cyber-attacks against electric grids to blackout and collapse entire nations. Iranian military doctrine makes no distinction between nuclear EMP weapons, non-nuclear radio-frequency weapons and cyber-operations—it regards nuclear EMP attack as the ultimate cyber weapon.*[14]

EMP is most effective at blacking-out critical infrastructures, while it does not directly damage the environment or harm human life, according to Iran's Passive Defense:

> *As a result of not having the other destructive effects that nuclear weapons possess, among them the loss of human life, weapons derived from electromagnetic pulses have attracted attention with regard to their use in future wars...The superficiality of secondary damage sustained as well as the*

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11 Ibid.

12 Li Bingyan, "General Trend of the Worldwide Revolution in Military Affairs and the Form of Future War" Guangming Ribao Online (January 27, 2016).

13 Army of the Islamic Republic of Iran, *Passive Defense: Approach to the Threat Center* (Tehran: Martyr Lt. General Sayad Shirazi Center for Education and Research, Spring 2010).

14 "A Shariah-Approved Nuclear Attack" Washington Times, September 15, 2015.

> *avoidance of human casualties serves as a motivation to transform this technology into an advanced and useful weapon in modern warfare.*[15]

Former CIA Director Woolsey notes: "Because EMP destroys electronics directly, but people indirectly, it is regarded by some as Shariah-compliant use of a nuclear weapon. *Passive Defense* and other Iranian military writings are well aware that nuclear EMP attack is the most efficient way of killing people, through secondary effects, over the long run. The rationale appears to be that people starve to death, not because of EMP, but because they live in materialistic societies dependent upon modern technology."[16]

An Iranian political-military journal, in an article entitled "Electronics To Determine Fate Of Future Wars," states that the key to defeating the United States is EMP attack and that, "If the world's industrial countries fail to devise effective ways to defend themselves against dangerous electronic assaults, then they will disintegrate within a few years…":

> *Advanced information technology equipment exists which has a very high degree of efficiency in warfare. Among these we can refer to communication and information gathering satellites, pilotless planes, and the digital system.... Once you confuse the enemy communication network you can also disrupt the work of the enemy command and decision-making center. Even worse, today when you disable a country's military high command through disruption of communications you will, in effect, disrupt all the affairs of that country.... If the world's industrial countries fail to devise effective ways to defend themselves against dangerous electronic assaults, then they will disintegrate within a few years.... American soldiers would not be able to find food to eat nor would they be able to fire a single shot.*[17]

Ironically, while electric power lobbyists are resisting EMP protection of the U.S. grid in Washington, the Iranian Mehr News Agency reported that Iran is violating international sanctions and going full bore to protect itself from a nuclear EMP attack:

> *Iranian researchers...have built an Electromagnetic Pulse (EMP) filter that protects country's vital organizations against cyber attack. Director of Kosar Information and Communication Technology Institute Saeid Rahimi told [Mehr News Agency] MNA correspondent that the EMP (Electromagnetic Pulse) filter is one of the country's boycotted products and until now procuring it required considerable costs and various strategies.* "*But recently Kosar ICT...has managed to domestically manufacture the EMP filter for the very first time in*

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15 Ibid.
16 Ibid
17 Tehran, Nashriyeh-e Siasi Nezami, December 1998 -January 1999.

this country," said Rahimi. Noting that the domestic EMP filter has been approved by security authorities, Rahimi added "the EMP filter protects sensitive devices and organizations against electromagnetic pulse and electromagnetic terrorism." He also said the domestic EMP filter has been implemented in a number of vital centers in Iran.[18]

North Korea

North Korea appears to have practiced the military doctrines described above against the United States—including possibly by simulating a nuclear EMP attack and Combined-Arms Cyber Warfare operation against the U.S. mainland.[19]

Following North Korea's third illegal nuclear test in February 2013, North Korean dictator Kim Jong-Un repeatedly threatened to make nuclear missile strikes against the U.S. and its allies. In what was then the worst ever nuclear crisis with North Korea, that lasted months, the U.S. responded by beefing-up National Missile Defenses and flying B-2 bombers in exercises just outside the Demilitarized Zone to deter North Korea.[20]

On April 16, 2013, North Korea's KMS-3 satellite orbited over the U.S. from a south polar trajectory, over-flying the Washington, DC-New York City corridor, the nation's political and economic capitals, from the south. [redacted] On April 16, KMS-3's trajectory was near optimal to make an EMP attack that could blackout the Eastern Grid that services half of the United States—if the satellite is nuclear-armed. On that same day, parties unknown used AK-47s to make a sophisticated commando-style attack on the Metcalf transformer substation, which services San Francisco and the Silicon Valley, an important part of the Western grid. Cyber-attacks on U.S. critical infrastructures continued throughout the crisis.[21]

On January 6, 2016, North Korea provoked another nuclear crisis with its fourth illegal nuclear test of what it claimed was an H-Bomb. On February 7th, again amidst threats to make a nuclear

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18 "Iran Builds EMP Filter For 1st Time" Mehr News Agency, June 13, 2015.

19 "EMP Threat from North Korea, 2013" Family Security Matters, April 27, 2014.

20 "U.S. Warns North Korea With Stealth Bomber Flights" Wall Street Journal, March 29, 2013.

21 "EMP Threat from North Korea, 2013" op. cit.; KMS-3 is NORAD's acronym for North Korea's satellite Kwangmyongsong-3 (Lodestar-3 or Guiding Star-3), a name richly symbolic for Korean mythology and the deification of Kim Jong-Un who according to official propaganda was born on Mt. Paeku under a newly appeared bright guiding star, signifying the birth of a great general. KMS-3 was launched on December 12, 2013, exactly two months before, and probably in anticipation of, North Korea's illegal nuclear test on February 12, 2013.

Are North Korea's Satellites an EMP Threat?

North Korea's KMS-3 and KMS-4 satellites orbit over the U.S. daily. [redacted] Their trajectory is similar to that planned for a Soviet-era secret weapon called the Fractional Orbital Bombardment System (FOBS) deployed by the USSR to make a surprise nuclear attack on the United States. In 2004, two retired Russian generals, then teaching at Russia's Voroshilov General Staff Academy, told the EMP Commission that the design for Russia's Super-EMP nuclear weapon was accidentally transferred by Russian scientists and engineers working on North Korea's missile and nuclear weapons program. They said North Korea could test a Super-EMP weapon "in a few years." The 2006 and subsequent low-yield tests do not appear to have been failures because North Korea proceeded with weaponization. In 1997, Andrey Kokoshin, then Russia's First Deputy Defense Minister, stated Russia was deploying a new generation of advanced nuclear weapons "that have no counterparts in the world" including EMP weapons and "ultra-small warheads weighing less than 90 kilograms." Such weapons would be small enough for North Korea's satellites. General Vladimir Slipchenko and General Vladimir Belous, who warned the EMP Commission about North Korean development of Super-EMP weapons, are among Russia's most prominent military scientists and experts on EMP and advanced technology warfare. General Slipchenko's advocacy of EMP and Combined-Arms Cyber Warfare is recognized in Iran's military textbook *Passive Defense* that advocates development of capabilities for nuclear EMP attack.

missile strike on the United States, Pyongyang orbited another satellite, the KMS-4, on the same polar trajectory as the KMS-3.[22]

Kim Jong-Un has threatened to reduce the United States to "ashes" with "nuclear thunderbolts" and threatened to retaliate for U.S. diplomatic and military pressure by "ordering officials and scientists to complete preparations for a satellite launch as soon as possible" amid "the enemies' harsh sanctions and moves to stifle" the North.[23] North Korean press asserts readiness for "any form of war" and includes their satellite with "strengthening of the nuclear deterrent and legitimate artificial satellite launch, which are our fair and square self-defensive choice." Moreover: "The nuclear [weapons] we possess are, precisely, the country's sovereignty, right to live, and dignity. Our satellite that cleaves through space is the proud sign that unfolds the future of the most powerful state in the world." The same article, like many others, warns North Korea

[22] "North Korea May Have Tested Components of A Hydrogen Bomb" CNN, January 29, 2016; "North Korea Launches 'Satellite," Sparks Fears About Long-Range Missile Program" Washington Post, February 6, 2016.

[23] Alex Lockie, "North Korea Threatens 'Nuclear Thunderbolts' as U.S. And China Finally Work Together" American Military News (April 14, 2017); Fox News, "U.S. General: North Korea 'Will' Develop Nuclear Capabilities to Hit America" (September 20, 2016) www.foxnews.com/world/2016/09/20/north-korea-says-successfully-ground-tests-new-rocket-engine.html

makes "constant preparations so that we can fire the nuclear warheads, which have been deployed for actual warfare for the sake of national defense, at any moment!"[24]

On April 30, 2017, South Korean officials told The Korea Times and YTN TV that North Korea's test of a medium-range missile on April 29 was not a failure, as widely reported in the world press, because it was deliberately detonated at 72 kilometers altitude. [redacted] According to South Korean officials, "It's believed the explosion was a test to develop a nuclear weapon different from existing ones." Japan's Tetsuro Kosaka wrote in Nikkei, "Pyongyang could be saying, 'We could launch an electromagnetic pulse (EMP) attack if things get really ugly.'"[25]

On September 3, 2017, North Korea conducted its sixth underground nuclear test. The test produced a seismic signal of 6.3 on the Richter scale, indicating a yield of over 100 kilotons. Shortly after that test, North Korea released an article titled "Kim Jong Un Gives Guidance to Nuclear Weaponization," which contained the following paragraph: **"The H-bomb, the explosive power of which is adjustable from tens kiloton to hundreds kiloton, is a multifunctional thermonuclear nuke with great destructive power which can be detonated even at high altitudes for super-powerful EMP attack according to strategic goals."** On September 4, 2017, Pyongyang published a technical report "The EMP Might of Nuclear Weapons" accurately describing what the Russians and Chinese call a Super-EMP nuclear weapon. These warnings leave little room for wishful thinking by the U.S. leadership.[26]

24 Rodong Sinmun (March 7, 2016).
25 Tetsuro Kosaka, "North Korea's 'Failed' Missile Test May Have Been a Thinly Disguised Threat," Nikkei (May 2, 2017).
26 Kim Song-won, "The EMP Might of Nuclear Weapons," Rodong Sinmun, Pyongyang, (September 4, 2017).

Non-Nuclear EMP Weapons

Terrorists, criminals, and even disgruntled individuals have already made localized EMP attacks using radio frequency weapons (RFWs) in Europe and Asia. Probably sooner rather than later, the RFW threat will come to America.

RFWs typically are much less powerful than nuclear weapons and much more localized in their effects, usually having a range of one kilometer or less. And unlike damage from guns and bombs, an attack by RFWs is much less conspicuous, and may even be misconstrued as an unusual accident arising from faulty components and systemic failure.

Some documented examples of successful attacks using Radio Frequency Weapons, and accidents involving electromagnetic transients, are described in the DoD *Pocket Guide for Security Procedures and Protocols for Mitigating Radio Frequency Threats*.[27]

For example, North Korea used a Radio Frequency Weapon, purchased from Russia, to attack airliners and impose an "electromagnetic blockade" on air traffic to Seoul, South Korea's capitol. The repeated attacks by RFW also disrupted communications and the operation of automobiles in several South Korean cities in December 2010; March 9, 2011; and April-May 2012.[28]

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27 U.S. Department of Defense, "*Pocket Guide for Security Procedures and Protocols for Mitigating Radio Frequency Threats* (Technical Support Working Group, Directed Energy Technical Office, Dahlgren Naval Surface Warfare Center).

28 "Massive GPS Jamming Attack by North Korea" GPSWORLD.COM (May 8, 2012).

Physical Attacks on Power Grids

On April 16, 2013, parties unknown used AK-47s to attack the Metcalf transformer substation that services San Jose, the Silicon Valley, and is an important part of the Western Grid. Blackout of the Western Grid could impede U.S. power projection capabilities against North Korea.

Cases of physical sabotage of electric power grids include the following:

- On October 27, 2013, the Knights Templars, a terrorist drug cartel, used explosives and small arms to blackout Mexico's Michoacan State, putting 420,000 people into the dark, isolating them from federal police, so they could publicly assassinate town and village leaders opposed to the drug trade.
- On June 9, 2014, Al Qaeda in The Arabian Peninsula (AQAP) used rocket-propelled grenade launchers to attack powerline towers, blacking-out all of Yemen, a nation of 16 cities and 24 million people. It is the first time in history terrorists have blacked-out an entire nation.
- On January 25, 2015, the Taliban blacked-out most of the electric grid in Pakistan, a nuclear weapons state.

All of these blackouts were temporary, caused by sabotage of powerlines or small substations. A coordinated attack on a relatively small number of the most important transformer substations could cause a protracted blackout lasting months. The Wall Street Journal has reported that a study by the U.S. FERC concluded that a terrorist attack that destroys just 9 key transformer substations could cause a protracted nationwide blackout.[29]

[29] Pry, *Blackout* Wars, op. cit.; Rebecca Smith, "Assault on California Power Station Raises Alarm on Potential for Terrorism" Wall Street Journal, February 5, 2014.

Cyber-Attacks on Power Grids

Suspected and known cases of cyber-attacks causing blackouts of power grids include the following:

- On March 31, 2015, Turkey's national electric grid was temporarily blacked-out, briefly causing widespread chaos to businesses and society in a NATO member and crucial U.S. Middle Eastern ally. Reportedly, Iran caused the blackout by a cyber-attack. Weeks later, amidst a confrontation with Russia over shooting down a Russian jet that violated Turkish airspace, Turkey denied being victimized by an Iranian cyber-blackout. If Iran was the culprit, it would be the first time in history that a nationwide blackout resulted from cyber warfare.
- On December 23, 2015, a partial blackout of Ukraine's electric grid that lasted 1 to 6 hours, affecting 230,000 people, is widely regarded as the first confirmed case of a successful cyber-attack on an electric grid. The cyber-blackout is attributed to Russia.
- A year later, on December 17, 2016, Ukraine was again victimized, allegedly by Russians disrupting power grid control systems to temporarily blackout over 100 cities and towns.

Cyber-attacks, the use of computer viruses and hacking to invade and manipulate information and SCADA systems, is described by some U.S. political and military leaders as one of the greatest threats facing the United States. Every day, literally thousands of cyber-attacks are made on U.S. civilian and military systems, most of them designed to steal information.

Then Joint Chiefs Chairman, General Martin Dempsey, warned on June 27, 2013, that the United States must be prepared for the revolutionary threat represented by cyber warfare: "One thing is clear. Cyber has escalated from an issue of moderate concern to one of the most serious threats to our national security," cautioned Chairman Dempsey, "We now live in a world of weaponized bits and bytes, where an entire country can be disrupted by the click of a mouse."[30]

On July 6, 2014, reports surfaced that Russian intelligence services allegedly infected 1,000 power plants in Western Europe and the United States with a new computer virus called Dragonfly. No one has stated what Dragonfly is supposed to do. Some analysts think it was just probing the defenses of western electric grids. Others think Dragonfly may have inserted logic bombs into SCADA systems that can disrupt the operation of electric power plants in a future crisis.

Tomorrow's cyber super-threat, that with computer viruses and hacking alone can blackout the national electric grid for a year or more, may already be upon us today.

[30] Claudette Roulo, *DoD News*, Armed Force Press Service, June 27, 2013.

Admiral Michael Rogers on November 20, 2014, warned the House Permanent Select Committee on Intelligence that sophisticated great powers like China and Russia have the capability to blackout the entire U.S. national electric grid for months or years by means of cyber-attack, according to press reports. Admiral Rogers, as Chief of U.S. Cyber Command and Director of the National Security Agency, is officially the foremost U.S. authority on the cyber threat. "It is only a matter of the when, not if, that we are going to see something traumatic," Admiral Rogers testified to Congress.[31]

In June 2015, congressional hearings revealed the discovery, about a year earlier, that China, probably the Chinese People's Liberation Army (PLA), hacked into computer files at the U.S. Office of Personnel Management and stole sensitive information on 30 million federal employees and U.S. citizens.

Russia apparently made a cyber-attack on the U.S. Joint Chiefs of Staff in July 2015 that crippled an unclassified e-mail communications network used by the Joint Chiefs. "The U.S. military believes hackers connected to Russia are behind the recent intrusion into a key, unclassified e-mail server used by the office of the Joint Chiefs," according to press reports, "Military officials assessed the attack had a sophistication that indicates it came from a state-associated actor." The widely reported Russian cyber-attack on the Joint Chiefs disrupted e-mail communications for 4,000 users at the Defense Department for over 10 days.[32]

In April 2015, another Russian cyber-attack reportedly penetrated "sensitive parts of the White House computer system."[33]

Few Americans make any connection between cyber-thefts and intrusions, such as those described above, and EMP attacks on the grid that could threaten the existence of society. But in the context of foreign military doctrine on Information Warfare, these cyber-thefts and intrusions look less like isolated cases of hacking and more like systematic probing of U.S. defenses and gauging Washington's reactions—perhaps in preparation for an all-out cyber offensive that would include physical sabotage, radiofrequency weapons, and nuclear EMP attack. In Nazi Germany's blitzkrieg strategy, the massed onslaught of heavy armored divisions was preceded by scouting and probing by their motorcycle corps. The same principle may be at work here in cyber space with probing attacks on the U.S. from China, Russia, North Korea and Iran.

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31 CNN November 21, 2014. However, Jonathan Pollett, a cyber-security expert, in an article challenged Admiral Rogers' warning as wrong, or misunderstood and exaggerated by the press: "No, hackers can't take down the entire, or even a widespread portion of the U.S. electric grid. From a logistical standpoint, this would be far too difficult to realistically pull off," writes Pollett in "What Hackers Can Do To Our Power Grid," Business Insider (November 23, 2014).

32 CNN, "Official: Russia Suspected In Joint Chiefs E-mail Server Intrusion," August 7, 2015.

33 Ibid.

All Hazards Strategy

We recommend an "all hazards" strategy to protect the nation by addressing the worst threat—nuclear EMP attack. Nuclear EMP is worse than natural EMP because it combines several threats in one. Nuclear EMP has a long-wavelength component like a geomagnetic super-storm, a short-wavelength component like Radio-Frequency Weapons, a mid-wavelength component like lightning—and is potentially more widespread and can do more damage than all three. Measures to protect electric grids and other critical infrastructures from EMP can also be designed to make these systems more resilient against cyber-attacks, sabotage, and severe weather.

A U.S. Army War College Study, *"In The Dark: Planning for a Catastrophic Critical Infrastructure Event,"* (2011) warned U.S. Cyber Command that U.S. doctrine should not overly focus on computer viruses to the exclusion of EMP attack and the full spectrum of other threats, as planned by potential adversaries.

Reinforcing the above, a Russian technical article on cyber warfare notes that a cyber-attack can collapse "the system of state and military control...its military and economic infrastructure" because of "electromagnetic weapons...an electromagnetic pulse acts on an object through wire leads on infrastructure, including telephone lines, cables, external power supply and output of information."[34]

Resilient Military Systems and the Advanced Cyber Threat, a January 2013 study by the Defense Science Board, recommends that it may be necessary for the U.S. to respond to an all-out cyber warfare operation with nuclear deterrence—or nuclear war. The Defense Science Board warns that while operationally "a nuclear and cyber-attack are very different" in terms of the consequences "the existential impact to the United States is the same."

The Defense Science Board likewise warns that cyber warfare is not only about computer viruses and hacking, but becomes an existential threat "from a sophisticated and well-resourced opponent utilizing cyber capabilities in combination with all of their military and intelligence capabilities (a "full spectrum" adversary)."

[34] Maxim Shepovalenko, Military-Industrial Courier (July 3, 2013).

Misinformation about EMP and the North Korean Threat

EMP non-experts often dismiss the possibility of a nuclear EMP attack from North Korea as "science fiction" and "unlikely" because either they lack knowledge of the effects of the Soviet and U.S. high altitude nuclear tests in the early 1960s, do not have access to or understand the extensive body of testing and analysis carried out by the DoD over the last fifty-five years, or they mistakenly believe the nuclear weapons currently possessed by North Korea are incapable of making an effective EMP attack.

One EMP skeptic correctly implies in his article that it is analytically risky to draw conclusions about the EMP threat when so much of the data is classified. It is riskier still for analysts with no technical training on EMP and without working professionally in the defense or intelligence communities on the EMP threat, to conclude the EMP threat is not real—dismissing the consensus view of EMP experts who have advanced degrees in physics and electrical engineering, have worked on EMP generation and effects for several decades, have throughout that time had access to classified data, and have conducted simulated EMP tests on a wide variety of electronic systems, beginning in 1963.

I offer this commentary to correct errors of fact, analysis, and myths about EMP and the threat from North Korea:

- Even primitive, low-yield nuclear weapons are such a significant EMP threat that rogue states or terrorists may well prefer using a nuclear weapon for EMP attack, instead of destroying a city: "Therefore, terrorists or state actors that possess relatively unsophisticated missiles armed with nuclear weapons may well calculate that, instead of destroying a city or military base, they may obtain the greatest political-military utility from one or a few such weapons by using them—or threatening their use—in an EMP attack."[35]
- North Korea may either now or in the future be armed with what the Russians call "Super-EMP" weapons, that can generate extraordinarily high-intensity EMP fields, according to unclassified Russian sources up to 200,000 volts per meter.[36] In 2004, two Russian generals, both EMP experts, warned the EMP Commission that the design for Russia's Super-EMP warhead was "accidentally" transferred to North Korea, and that due to "brain drain" Russian scientists were in North Korea, helping with their missile and nuclear weapon programs. South Korean military intelligence told their press that Russian scientists are in North Korea helping develop an EMP nuclear weapon. In 2013, a People's Republic of China military commentator stated North Korea has Super-EMP nuclear weapons. The EMP Commission 2004 Report warns: "Certain types of relatively

[35] EMP Commission *Executive Report 2004*, p. 2.

[36] "Russia: Nuclear Response To America Is Possible Using Super-EMP Factor," Aleksey Vaschenko, "A Nuclear Response To America Is Possible" Zavtra (November 1, 2006).

low-yield nuclear weapons can be employed to generate potentially catastrophic EMP effects over wide geographic areas, and designs for variants of such weapons may have been illicitly trafficked for a quarter-century."[37]

- Super-EMP weapons are low-yield and designed to produce not a big kinetic explosion, but rather a high level of gamma rays, which is what generates the high-frequency E1 EMP most damaging to the broadest range of electronics. North Korean nuclear tests, including the first in 2006, whose occurrence was predicted to the EMP Commission two years in advance and by the two Russian EMP experts, are consistent with testing of a Super-EMP weapon.
- The design of a Super-EMP weapon could be relatively small and lightweight. Such a device could fit inside North Korea's satellites that can orbit over the United States. [redacted], resembling a Russian secret weapon developed during the Cold War that could have used a nuclear-armed satellite to make a surprise EMP attack on the United States.
- One popular myth is that during the 1962 STARFISH PRIME high-altitude nuclear test "just one string of street lights failed in Honolulu" and that the test proves EMP is no threat. In fact, the EMP knocked-out thirty-six strings of street lights, caused a telecommunications microwave relay station to fail, burned out high-frequency radio links, set off burglar alarms, and caused other damage. The Hawaiian Islands did not experience a catastrophic protracted blackout because they were on the far edge of the EMP field contour, where effects are weakest, and were still in an age dominated by vacuum tube electronics. In addition, the slow pulse (E3) component of the EMP waveform couples most effectively to very long electric power transmission lines present on large land masses but not present in Hawaii. A 1983 twelve-page report, formerly classified Confidential Restricted Data, summarizing the observed EMP effects of the Fishbowl U.S. exo-atmospheric tests, has recently been reviewed at the request of the EMP Commission and found to be unclassified, but has been placed under a distribution restriction by the Department of Defense that makes it unavailable to analysts and others concerned about the viability of U.S. critical national infrastructure. No justification for the distribution restriction has been given.
- Russia in 1961-62 conducted a series of high-altitude EMP tests over Kazakhstan, an industrialized area nearly as large as Western Europe, that damaged the Kazakh electric grid. Modern electronics are much more vulnerable to EMP than the electronics of 1962 exposed to STARFISH PRIME and the Kazakh nuclear tests. A similar EMP event over the U.S. today would be an existential threat to our society, due to our dependence on the

[37] EMP Commission *Executive Report 2004,* p. 2. Kim Min-sek and Yoo Jee-ho, "Military Source Warns of North's EMP Bomb" JoonAng Daily (September 2, 2009). Li Daguang, "North Korea Electromagnetic Attack Threatens South Korea's Information Warfare Capabilities" Tzu Chin, No. 260 (Hong Kong: June 1, 2012), in "PRC Owned HK Journal Says DPRK May Build EMP Bombs To Paralyze ROK Weapons System."

electric power grid and other lifeline infrastructures, all the more susceptible due to the vulnerability of advanced electronic controls and communications.

- One popular but poorly informed author mistakenly inferred from a single simulated EMP test series on vehicles that, because only 6 of 55 vehicles were shut down, vehicle transportation would continue after an EMP event. During that test one of the vehicles was damaged and could not be operated until repaired, indicating that at least 2 percent of vehicles would be at risk of EMP damage. Even a 2 percent failure rate of vehicles would cause traffic jams, crippling transportation in urban areas. Moreover, the EMP test protocol limited testing vehicles only to upset, not to damage, because the EMP Commission could not afford to repair damaged cars; however, one vehicle was damaged by EMP despite best efforts to limit the effects to upset. Several of the vehicles tested stopped operating but could be restarted. Over 50 years of EMP testing indicates that full field damage to vehicles would probably be much higher than was observed on the limited tests. Today's vehicles depend on a much larger complement of electronics than the vehicles tested by the Commission more than a decade ago. Furthermore, vehicles cannot run without fuel, which cannot be pumped in a protracted electrical blackout.
- Another poorly informed analyst wondered why EMP from atmospheric nuclear tests in Nevada did not blackout Las Vegas. The nuclear tests he describes were all endo-atmospheric tests that do not generate appreciable EMP fields beyond a range of about 5 miles. The HEMP threat of interest requires exo-atmospheric detonation, at 30 kilometers altitude or above, and produces EMP out to ranges of hundreds to thousands of miles, depending on the height of detonation. Las Vegas was not affected by EMP because those endo-atmospheric nuclear tests generated much lower level fields outside the Nevada Test Site.
- Another poorly informed author miscalculates that "a 20-kiloton bomb detonated at optimum height would have a maximum EMP damage distance of 20 kilometers" in part because he mistakenly assumes "15,000 volts/meter or higher" in the E1 EMP extends only a short distance from the detonation point and that field strength is necessary for damage. These figures are extreme underestimates of the EMP field range and an extreme overestimate of system damage field thresholds. A one meter wire connected to a semiconductor device, such as a mouse cord or interconnection cable, would place hundreds to thousands of volts on microelectronic devices out to ranges of hundreds of miles for low-yield exo-atmospheric detonations. Semiconductor junctions operate at a few volts, and will experience breakdown at a few volts over their operating point, then allowing their power supply to destroy junctions experiencing reverse bias breakdown, as has been our experience in many EMP tests.
- The North Korean missile test on April 29, 2017, that apparently either failed or deliberately detonated at an altitude of 72 kilometers [redacted] could have been a test for creating a potentially damaging EMP field to a distance, not of one ill-informed author's miscalculated 20

kilometers, but of about 930 kilometers [Kilometers Radius = 110 (Kilometers Burst Height to the 0.5 Power)].

- Ill-informed authors often mistakenly ignore system upset as a vulnerability. Digital electronics can be upset by extraneous pulses of a few volts. For unmanned control systems present within the electric power grid, long-haul communication repeater stations, and gas pipelines, an electronic upset can be tantamount to permanent damage. Temporary upset of electronics can also have catastrophic consequences for military operations. No electronics should be considered invulnerable to EMP unless hardened or tested to certify survivability. Some highly critical unprotected electronics have been upset or damaged in simulated EMP tests, not at one author's alleged "15,000 volts/meter or higher" but at threat levels far below 1,000 volts/meter.

Therefore, even for a low-yield 10 to 20 kiloton weapon, the EMP field should be considered dangerous for unprotected U.S. systems. The EMP Commission 2004 Report warned against the U.S. military's increasing use of commercial-off-the-shelf-technology that is not protected against EMP: "Our increasing dependence on advanced electronics systems results in the potential for an increased EMP vulnerability of our technologically advanced forces, and if unaddressed makes EMP employment by an adversary an attractive asymmetric option."[38]

[38] EMP Commission *Executive Report 2004*, p. 47.

North Korea Nuclear EMP Attack: An Existential Threat

While most military and other analysts are fixated on when in the future North Korea will develop highly reliable intercontinental missiles, guidance systems, and reentry vehicles capable of striking a U.S. city, the present and continuing threat from EMP is largely ignored. EMP attack does not require an accurate guidance system because the area of effect, having a radius of hundreds or thousands of kilometers, is so large. No reentry vehicle is needed because the warhead is detonated at high-altitude, above the atmosphere. Missile reliability matters little because only one missile has to work to make an EMP attack against an entire nation.

North Korea could make an EMP attack against the United States by ICBM, or by launching a short-range missile off a freighter or submarine or by lofting a warhead to 30 kilometers burst height by balloon. While such lower-altitude EMP attacks would not cover the whole U.S. mainland, as would an attack at higher-altitude (300 kilometers), even a balloon-lofted warhead detonated at 30 kilometers altitude could blackout the Eastern Grid that supports most of the population and generates 75 percent of U.S. electricity.

An EMP attack could also be made by a North Korean satellite.

North Korea's KMS-3 and KMS-4 satellites were launched to the south on polar trajectories and passed over the United States on their first orbit. Pyongyang launched KMS-4 on February 7, 2017, shortly after its fourth illegal nuclear test on January 6, 2017, that began the present protracted nuclear crisis with Pyongyang.

[redacted], resembling a Russian secret weapon developed during the Cold War, called the Fractional Orbital Bombardment System (FOBS) that would have used a nuclear-armed satellite to make a surprise EMP attack on the United States.[39]

Ambassador Henry Cooper, former Director of the U.S. Strategic Defense Initiative, and a preeminent expert on missile defenses and space weapons, has written numerous articles warning about the potential North Korean EMP threat from their satellites. For example, on September 20, 2016 Ambassador Cooper wrote:

> *U.S. ballistic missile defense (BMD) interceptors are designed to intercept a few North Korean ICBMs that approach the United States over the North Polar region. But current U.S. BMD systems are not arranged to defend against even a single ICBM that approaches the United States from over the South Polar region, which is the direction toward which North Korea launches its*

[39] Miroslav Gyurosi, *The Soviet Fractional Orbital Bombardment System Program*, (January 2010) Technical Report APA-TR-2010-010.

> *satellites…This is not a new idea. The Soviets pioneered and tested just such a specific capability decades ago—we call it a Fractional Orbital Bombardment System (FOBS)…So, North Korea doesn't need an ICBM to create this existential threat. It could use its demonstrated satellite launcher to carry a nuclear weapon over the South Polar region and detonate it…over the United States to create a high-altitude electromagnetic pulse (HEMP)…The result could be to shut down the U.S. electric power grid for an indefinite period, leading to the death within a year of up to 90 percent of all Americans—as the EMP Commission testified over eight years ago.*[40]

Former NASA rocket scientist James Oberg visited North Korea's Sohae space launch base, witnessed elaborate measures undertaken to conceal space launch payloads, and concludes in a 2017 article that the EMP threat from North Korea's satellites should be taken seriously:

> *…there have been fears expressed that North Korea might use a satellite to carry a small nuclear warhead into orbit and then detonate it over the United States for an EMP strike. These concerns seem extreme and require an astronomical scale of irrationality on the part of the regime. The most frightening aspect, I've come to realize, is that exactly such a scale of insanity is now evident in the rest of their "space program." That doomsday scenario, it now seems, has been plausible enough to compel the United States to take active measures to ensure that no North Korean satellite, unless thoroughly inspected before launch, be allowed to reach orbit and ever overfly the United States.*[41]

An earlier generation immediately understood the alarming strategic significance of Sputnik in 1957, yet few today understand the strategic significance of North Korea's satellites, perhaps because of widespread ignorance about EMP.

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40 Ambassador Henry F. Cooper, "Whistling Past The Graveyard…" High Frontier (September 20, 2016) highfrontier.org/sept-20-2016-whistling-past-the-graveyard. See also: highfrontier.org/category/fobs. On up to 90 percent U.S. fatalities from an EMP attack, see: U.S. House of Representatives, Hearing, "Threat Posed by Electromagnetic Pulse (EMP) Attack" Committee on Armed Services (Washington, D.C.: July 10, 2008), p. 9.

41 Jim Oberg, Space Review (February 6, 2017) www.thespacereview.com/article/3164/1in

The Fragility of Complex Systems

When assessing the potential vulnerability of U.S. military forces and civilian critical infrastructures to EMP, it is necessary to be mindful of the complex interdependencies of these highly-networked systems, such that EMP upset and damage of a very small fraction of the total system can cause total system failure.

Real world failures of electric grids from various causes indicate that a nuclear EMP attack would have catastrophic consequences. Significant and highly disruptive blackouts have been caused by single-point failures cascading into system-wide failures, originating from damage comprising far less than 1 percent of the total system. For example:

- The Great Northeast Blackout of 2003—that put 50 million people in the dark for a day, contributed to at least 11 deaths, and cost an estimated $6 billion—originated from a single failure point when a powerline contacted a tree branch, damaging less than 0.0000001 (0.00001 percent) of the system.
- The New York City Blackout of 1977, that resulted in the arrest of 4,500 looters and injury of 550 police officers, was caused by a lightning strike on a substation that tripped two circuit breakers.
- The Great Northeast Blackout of 1965, that affected 30 million people, happened because a protective relay on a transmission line was improperly set.
- India's nationwide blackout of July 30-31, 2012—the largest blackout in history, affecting 670 million people, 9 percent of the world population—was caused by overload of a single high-voltage powerline.
- India's blackout of January 2, 2001—affecting 226 million people—was caused by equipment failure at the Uttar Pradesh substation.
- Indonesia's blackout of August 18, 2005—affecting 100 million people—was caused by overload of a high-voltage powerline.
- Brazil's blackout of March 11, 1999—affecting 97 million people—was caused by a lightning strike on an EHV transformer substation.
- Italy's blackout of September 28, 2003—affecting 55 million people—was caused by overload of two high-voltage powerlines.
- Germany, France, Italy, and Spain experienced partial blackouts on November 4, 2006—affecting 10 to 15 million people—from accidental shutdown of a high-voltage powerline.
- The San Francisco blackout in April 2017 was caused by the failure of a single high voltage breaker at a substation.

In contrast to the above blackouts caused by single-point or small-scale failures, a nuclear EMP attack would inflict massive widespread damage to the electric grid causing a large number of

failure points. With few exceptions, the U.S. national electric grid is unhardened and untested against nuclear EMP attack.

In the event of a nuclear EMP attack on the United States, a widespread protracted blackout is inevitable. This commonsense assessment is also supported by the nation's best computer modeling:

Modeling by the U.S. FERC reportedly assesses that a terrorist attack that destroys just 9 EHV transformer substations would produce catastrophic damage, causing a protracted nationwide blackout.

Modeling by the EMP Commission assesses that a terrorist nuclear EMP attack, using a primitive 10-kiloton nuclear weapon, could destroy many EHV transformers and thousands of SCADA and electronic systems, causing catastrophic collapse and protracted blackout of the U.S. power grids, putting at risk the lives of millions.

For the best unclassified modeling assessments of likely damage to the U.S. national electric grid from nuclear EMP attack see the following: U.S. FERC Interagency Report, coordinated with the DoD and Oak Ridge National Laboratory: *Electromagnetic Pulse: Effects on the U.S. Power Grid, Executive Summary* (2010); U.S. FERC Interagency Report by Edward Savage, James Gilbert and William Radasky, *The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid* (Meta-R-320) Metatech Corporation (January 2010); U.S. FERC Interagency Report by James Gilbert, John Kappenman, William Radasky, and Edward Savage, *The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid* (Meta-R-321) Metatech Corporation (January 2010).

Regulatory Failures by the U.S. Federal Energy Regulatory Commission, the North American Energy Regulatory Corporation, and the Electric Power Industry

The current largely self-regulatory structure of the U.S. Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), and the electric power industry was not designed to address U.S. survival under nuclear EMP or other hostile attack. The Commission assesses that the existing regulatory framework for safeguarding the security and reliability of the electric power grid, which is based upon a partnership between the U.S. FERC and the private NERC representing the utilities, is not able to protect the U.S. against hostile attack. The U.S. FERC and NERC standards for protecting the power grids from geomagnetic disturbances caused by solar storms are also inadequate to address storms of historical record.[42]

The U.S. FERC, the U.S. government agency that is supposed to partner with NERC in protecting the national electric grid, has publicly testified before Congress that the U.S. FERC lacks regulatory power to compel NERC and the electric power industry to protect the grid from natural and nuclear EMP and other threats.

Consider the contrast in regulatory authority between the U.S. FERC and, as examples, the U.S Nuclear Regulatory Commission (NRC), the U.S. Federal Aviation Administration (FAA), the U.S. Department of Transportation (DOT), or the U.S. Food and Drug Administration (FDA):

- The NRC has regulatory power to compel the nuclear power industry to incorporate nuclear reactor design features to make nuclear power safe. (To date, however, the NRC has not incorporated EMP survival criteria into its regulations. By the NRC's failure to use its authority to mandate protection from EMP of U.S. nuclear reactor control, safe shutdown, cooling, and other reactor systems and spent fuel storage systems, the NRC continues to place at risk the safety and survivability of the 99 U.S. commercial power reactors in operation and the safety of the people living in the vicinity of these reactors.)
- The FAA has regulatory power to compel the airlines industry to ground aircraft considered unsafe, to change aircraft operating procedures considered unsafe, and to make repairs or improvements to aircraft in order to protect the lives of passengers.
- The DOT has regulatory power to compel the automobile industry to install on cars safety glass, seatbelts, and airbags in order to protect the lives of the driving public.

[42] John G. Kappenman and Dr. William Radasky, *Examination of NERC GMD Standards and Validation of Ground Models and Geo-Electric Fields* (Storm Analysis Consultants and Metatech Corporation, July 30, 2014) adopted as an EMP Commission Staff Paper. See also Foundation for Resilient Societies, Comments Submitted on Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events, U.S. FERC Docket No. RM15-11-000, July 27, 2015; supplementary comments submitted August 10, 2015.

Underestimating the EMP Threat to Transformers

The most recent example of industry inadequacy as a champion for EMP preparedness is a study by EPRI that purports to prove a nuclear EMP attack would destroy few, if any EHV transformers. I have reviewed this study and find many flaws in the EPRI assessment. Contrary to EPRI, many EHV transformers would be at risk from the same nuclear EMP attack postulated by EPRI. The EMP Commission has produced a report providing a more realistic assessment of the E3 EMP field strengths likely to be generated by a nuclear EMP attack. The Commission's unclassified assessment of the E3 EMP threat should better inform the electric power industry and other private sector critical infrastructures so they can better protect themselves. See the EMP Commission Report by Dr. Edward B. Savage and Dr. William A. Radasky, *Development of Estimates of Peak Values of the Late-Time (E3) HEMP Heave Electric Fields Using Measured Data from High Altitude Nuclear Testing* (Metatech: Meta-R-440, July 10, 2017).

- The FDA has power to regulate the quality of food and drugs, and can ban under criminal penalty the sale of products deemed by the FDA to be unsafe to the public.

Unlike the NRC, FAA, DOT, FDA or any other U.S. government regulatory agency, the U.S. FERC does not have legal authority to compel the industry it is supposed to regulate to act in the public interest. For example, the U.S. FERC lacks legal power to direct NERC and the electric utilities to install devices to protect the grid.

Currently, the U.S. FERC only has the power to ask NERC to propose a Standard to protect the grid. NERC standards are approved, or rejected, by its membership, which is largely made up of representatives from the electric power industry. Once NERC proposes a Standard to the U.S. FERC, the FERC cannot modify the Standard, but must accept or reject the proposed Standard. If the U.S. FERC rejects the proposed Standard, NERC goes back to the drawing board, and the process starts all over again.

The geomagnetic disturbance standards proposed by the NERC that the U.S. FERC has adopted to date substantially underestimate the problem, and no standards for protecting the grid against nuclear or non-nuclear EMP weapons have been proposed or adopted.

Regulatory inadequacy over the electric power industry for national security is demonstrated, not only in the failure of industry to protect the grid, but in lobbying by NERC, EPRI, EEI and other industry groups to oppose initiatives by federal and state officials and private citizens to protect the grid from EMP over the past 9 years by implementing the recommendations of the EMP Commission made in 2008. Texas State Senator Bob Hall speaks for many Americans frustrated by the electric power industry's active, and frequently misleading, opposition:

> *As a Texas State Senator who tried in the 2015 legislative session to get a bill passed to harden the Texas grid against an EMP attack or nature's GMD, I*

learned first-hand the strong control the electric power company lobby has on elected officials. We did manage to get a weak bill passed in the Senate but the power companies had it killed in the House. A very deceitful document which was carefully designed to mislead legislators was provided by the power company lobbyist to legislators at a critical moment in the process. The document was not just misleading, it actually contained false statements. The EMP/GMD threat is real and it is not "if" but WHEN it will happen. The responsibility for the catastrophic destruction and wide spread death of Americans which will occur will be on the hands of the executives of the power companies because they know what needs to be done and are refusing to do it. In my opinion power company executives, by refusing to work with the legislature to protect the electrical grid infrastructure are committing an egregious act that is equivalent to treason. I know and understand what I am saying. As a young U.S. Air Force captain, with a degree in electrical engineering from The Citadel, I was the project officer who lead the Air Force/contractor team which designed, developed and installed the modification to "harden" the Minuteman strategic missile to protect it from an EMP attack. The American people must demand that the power company executives that are hiding the truth stop deceiving the people and immediately begin protecting our electrical grid so that life as we know it today will not end when the terrorist EMP attack comes.

In March 2016, the U.S. GAO published a report with the (misleading) title *Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, But Opportunities Exist to Further Assess Risks and Strengthen Collaboration* (GAO-16-243). Appendices in the U.S. GAO report reveal that none of the essential measures recommended by the EMP Commission to protect the national electric grid have been undertaken:

Recommendation	**Action**
Expand and extend emergency power supplies	None
Extend black start capability	None
Prioritize and protect critical nodes	None
Expand and assure intelligent islanding capability	None
Assure protection of high-value generation assets	None
Assure protection of high-value transmission assets	None
Assure sufficient numbers of adequately trained recovery personnel	None

In the U.S. GAO report, the "actions" undertaken by federal agencies to address EMP are almost entirely studies and a few experimental programs.

During a hearing before the Senate Homeland Security and Government Affairs Committee (SHSGA) on July 22, 2015, under questioning by the Chairman, Senator Ron Johnson, the U.S.

GAO acknowledged that none of the recommendations of the EMP Commission to protect the national grid from EMP have been implemented by the U.S. Department of Homeland Security, U.S. Department of Energy, U.S. FERC, or NERC.

The U.S. GAO report explained lack of progress in protecting the national electric grid from EMP as due to a lack of leadership, because no one was in charge of solving the EMP problem: "DHS and DOE, in conjunction with industry, have not established a coordinated approach to identifying and implementing key risk management activities to address EMP risks."

The 2014 Intelligence Report

The report by the Joint Atomic Energy Intelligence Committee (JAEIC) on EMP issued in 2014 is factually erroneous and analytically unsound. I recommend that the Director of National Intelligence withdraw the JAEIC EMP Report and direct that the EMP Commission critique of the JAEIC EMP Report be circulated to all the recipients of the 2014 JAEIC EMP Report, which is a threat to national security by impeding progress on EMP understanding and protection.

Conclusions

The United States critical national infrastructure faces a present and continuing existential threat from combined-arms warfare, including cyber and manmade EMP attack, and natural EMP from a solar superstorm. During the Cold War, the U.S. was primarily concerned about a high altitude nuclear-weapon generated EMP attack as a tactic by which the Soviet Union could suppress the ability of the U.S. national command authority and U.S. strategic forces to respond to a nuclear attack, and thus destroy the U.S. deterrence provided by assured nuclear retaliation. Within the last decade, newly nuclear-armed adversaries, including North Korea, have been developing the ability and threatening to carry out an EMP attack against the U.S. Such an attack would give countries that have only a small number of nuclear weapons the ability to cause widespread, long-lasting damage to U.S. critical national infrastructures, to the United States itself as a viable country, and to the survival of a majority of its population.

While during the Cold War major efforts were undertaken by the DoD to assure that the U.S. national command authority and U.S. strategic forces could survive and operate after an EMP attack, no major efforts were then thought necessary by the national leadership to protect critical national infrastructures, provided that nuclear deterrence was successful. With the development of small nuclear arsenals and long-range missiles by small, hostile, potentially unstable and irrational countries, including North Korea, the threat of a nuclear EMP attack against the U.S. becomes one of the few ways that such a country could inflict devastating damage to the U.S. Therefore, it is urgent that the U.S. national leadership address the EMP threat as a critical, existential issue, and give a high priority to assuring the necessary leadership is engaged and the necessary steps are taken to protect the country from EMP. Otherwise, foreign adversaries may reasonably consider such an attack as one which can gravely damage the U.S. by striking at its technological Achilles' heel, without having to overcome the U.S. military.

Protecting and defending the national electric grid and other critical infrastructures from EMP attack could be accomplished at reasonable cost and minimal disruption to the present systems that comprise our critical infrastructure; all commensurate with Trump Administration plans to repair and improve U.S. infrastructures, increase their reliability, and strengthen our homeland defense and military capability. Continued failure to address our country's vulnerability to high altitude nuclear weapon-generated EMP invites attack.

Dr. William R. Graham
Chairman

Commission To Assess The Threat
To The United States From
Electromagnetic Pulse (EMP) Attack

Dr. William R. Graham served as President Ronald Wilson Reagan's White House Science Advisor, Acting Administrator of the National Aeronautics and Space Administration (NASA), and Chairman of the Congressional EMP Commission (the Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack, 2001-2017).

As a young defense scientist working for the U.S. Army, Dr. Graham was among the team that investigated and first discovered the EMP phenomenon in the aftermath of the 1962 STARFISH PRIME nuclear test and has been contributing to protection of U.S. military forces from EMP since 1963.

Dr. Graham is widely considered the Free World's foremost expert on EMP. Dr. Graham has served on several high-level study groups, including the Department of Defense Transformation Study Group, the Commission to Assess United States National Security Space Management and Organization (the Rumsfeld Commission on Space), and the Commission to Assess the Ballistic Missile Threat to the United States.

From 1986-1989 Dr. Graham was director of the White House Office of Science and Technology Policy while he served concurrently as Science Advisor to President Reagan, Chairman of the Federal Joint Telecommunications Resources Board, and member of the Arms Control Experts Group. Dr. Graham was also Chairman of the Board and Chief Executive Officer of National Security Research Inc. (NSR), a Washington-based company that conducts technical, operational, and policy research and analysis related to U.S. national security.